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ABSTRACT

The primary purpose of the 1994 Mathematics/Science Education and Technology Symposium was to help foster the exchange of information related to the research, development, and applications of learning and teaching using information technology in mathematics and science educations. The theme "Emerging Issues and Trends" was identified to encourage papers written on the rapidly changing technology and how this technology can help improve mathematics and science education. This proceedings contains 47 full papers and 15 demonstrations and posters. The following topics are addressed in the papers: visualizing polygonal numbers; artificial intelligence and statistics and arithmetic; computer-assisted instruction; Microworld; technology in first-year algebra; Mathematica and linear algebra; knowledge networks and biology; knowledge base representation for physics; calculator use in mathematics; graphical software; interactive learning; technology and staff development; integrated spreadsheet templates and problem solving; video networks; computers and science; technology and metacognition; computer literacy; electronic resources as instructional aids; spreadsheets and science; problem solving and technology; gender and science; instructional design; computers and calculus; technology and future teachers; technology and restructuring mathematics and science; teacher training; and technology and physics. Most of the papers contain references. (JLB)

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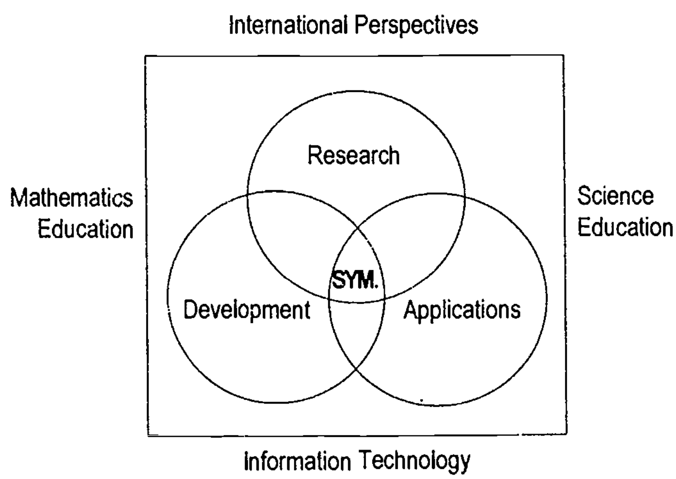
Preface

The 1994 International Symposium on Mathematics/Science Education and Technology is the first in a new series of biennial symposia sponsored by the *Journal of Computers in Mathematics and Science Teaching* (JCMST) and the Association for the Advancement of Computing in Education (AACE).

JCMST was established in 1981 as the first journal published by AACE. Now with six international journals and four conferences, AACE is for the first time offering a meeting for this initial division of the o. ganization—Computers in Math and Science Teaching Division.

Too often those who can influence the quality of math and science education work in isolation on at least three different dimensions: 1) researchers, developers, and practitioners, 2) disciplines such as mathematics, science, and computer science, and 3) various countries working in this field. Thus, the primary purpose of the Symposium is to help foster the exchangc of information related to the research, development, and applications of learning and teaching using information technology in mathematics and science education. This meeting is a unique international forum designed to bring together the ideas of these groups on an international scale, as depicted in the figure below.



The Symposium theme, "Emerging Issues and Trends," was identifed to reflect and encourage the submission of papers written on the rapidly changing technology and how this technology can help improve mathematics and science education.

This proceedings contains 47 full papers and 15 demonstrations and posters. The result is an interesting collection that helps to illuminate the issues and trends in the field. The contents of this volume demonstrate that advanced work is being carried out and the potential for future advances in the field is promising.

The Symposium organizers wish to thank all reviewers, the invited speakers—Art St. George (National Science Foundation, USA), Stephen Marcus (Univ. of California-Santa Barbara, USA), and Ricki Goldman-Segall (Univ. of British Columbia, Canada)—and the over 100 researchers and practitioners from around the world who participated in this first Symposium. It is you who have made this meeting a success.

Gary H. Marks
AACE Executive Director
July 1994

TABLE OF CONTENTS

Papers

Demonstrations/Posters

7

PAPERS

Exploring and Visualizing Properties of Polygonal Numbers in a Multiple-Application Computer-Enhanced Environment

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Abstract: Polygonal numbers can be motivated, discovered or developed from geometric, numerical or algebraic formulations. The paper demonstrates the use of multiple software tools to provide visualization in each of these approaches. The object is the understanding of polygonal numbers, developing recursive and closed-form expressions of polygonal numbers of arbitrary side and rank based on geometrical considerations, seeing the relationships among various formulations, and visualizing connection of polygonal numbers to primes. We argue that a multiple-application environment allows learners to recognize patterns and regularities among polygonal numbers, to make conjectures, and to test them through numerical evidence. Even though these are elementary conjectures their proof often requires more than elementary means and in these cases computer applications provide demonstration only. In some cases, however, demonstration through numerical evidence stimulates the development of mathematical proofs.

The National Council of Teachers of Mathematics Standards for Mathematics Curriculum give rise to approaches that redefine mathematics curricula and traditional teaching strategies. Technology as a tool for mathematics investigations brings about opportunities for new content, new curricula, and new teaching strategies. One such content area, which represents enjoyable mathematics with little previous knowledge, is elementary number theory. Before the theory of numbers became a scientific study people used simple visual patterns to portray numbers. The representation of numbers in simple geometric figures goes back to antiquity when certain numbers were noticed to have different characteristics from others. For example, a number of objects could be placed like pins in a bowling alley to form a triangle and in such a way the number becomes triangular. Because one and the same number may be represented by objects of different nature, this abstraction from visual images signifies a simple but very important generalization. In much the same way a number of objects can form other regular polygonal patterns which represent numbers known as square, pentagonal, hexagonal, etc. All these numbers are called polygonal numbers.

The study of polygonal numbers can be motivated by the use of technology. In the past, the use of computers in number theory investigations required skills in programming languages. The approach in this paper is to use newer software tools - dynamic geometry, relation graphers, and spreadsheets - to explore, investigate and discover properties of polygonal numbers, and to show their connection to other remarkable numbers, such as primes.

The dynamics of the development of polygonal patterns from sets of dots arranged in geometric patterns can be visualized with Geometer's Sketchpad - a dynamic software for exploring geometry on Macintosh computers. One can construct triangular, square, pentagonal, or hexagonal patterns in order to develop polygonal numbers of corresponding side as an abstraction from figures. The power of visualization provided by *Sketchpad*, makes it possible to study a general case of polygonal numbers of arbitrary side at an empirical, very intuitive level. Indeed, let us consider the *Sketchpad* sketch in Figure 1 as a model of polygonal numbers (in this case, hexagonal numbers) of side m. The goal is to give analytic formulations for these numbers.

The number of dots on each side of a polygon of n-th rank is exactly n. Denote P(m,n) as the polygonal number of side m and of rank n. Recursive counting of the dots suggests that the transfer from n-1 to n in the m-polygon increases the number of dots by (m-2)(n+1)+1. This leads to the following recursive definition of the polygonal number of side m and rank n

$$P(m,n) = P(m,n-1) + (m-2)(n-1) + 1, \qquad (1)$$

subject to the boundary condition

$$P(m,1) = 1 \text{ for all } m \geq 3 \qquad (2)$$

that is, every polygonal number of rank 1 is 1.

Relation 1 is a first order difference equation in variable n. The computational capacity of a spreadsheet allows modeling of difference equations in two integral variables. This provides the opportunity to study polygonal numbers through a numerical approach, i.e., to explore modeling data, discover numerical patterns in special cases and generalize from these.

One can also count the dots in an m-polygon of n-th rank by splitting the polygon into m-2 triangles of the same rank (see Figure 2). Each triangle contains $\frac{n(n+1)}{2}$ dots and the number of dots on each of m-3 overlapping sides is n. This way of counting dots suggests the following closed-form relation for the polygonal number of side m and rank n

$$P(m,n) = \frac{(m-2)n(n+1)}{2} - (m-3)n \qquad (3)$$

Note that due to Relation 3, P(m,1) = 1 and this coincides with Condition 2. The latter may be given the following geometric interpretation: all polygonal patterns of rank 1 are a single dot. Relation 3 allows the possibility to construct a spreadsheet-based Square Test (Beiler, 1966) for determining whether a number is a polygonal number:

The natural number N is a polygonal number of side m and rank n if and only if:
1) the number $8(m-2)N + (m-4)^2$ is a perfect square, and
2) the number $\dfrac{\sqrt{8(m-2)N + (m-4)^2} + m-4}{2(m-2)}$ is an integer number.

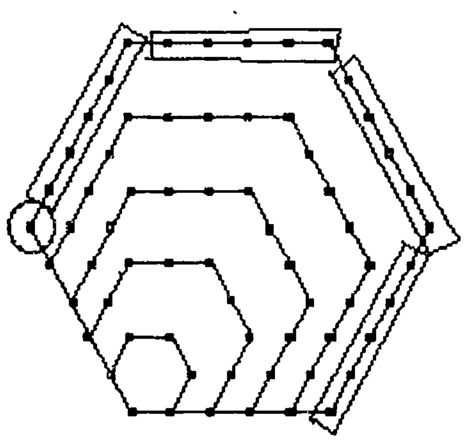

Figure 1. Visualization of recursive definition of polygonal numbers

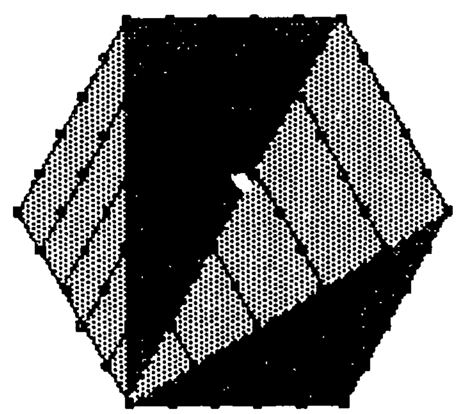

Figure 2. Visualization of explicit definition of polygonal numbers

Exploring properties of polygonal numbers

Multiple-application environment suggests different ways of representing polygonal numbers: (a) modeling Relation 1 subject to Condition 2; (b) modeling Relation 3; (c) modeling polygonal numbers through applying the Square Test to natural numbers. Each approach would make it possible to visualize polygonal numbers on the spreadsheet template. Different features of each representation would contribute to the enhancement of students' conjecturing of properties of these numbers and their discovering of connections between polygonal numbers and other remarkable integers.

m\n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	1																			
2	1																			
3	1	3	6	10	**15**	21	28	**36**	45	55	66	78	91	105	120	136	153	171	190	210
4	1	4	9	16	25	**36**	49	64	81	100	121	144	169	196	225	256	289	324	361	400
5	1	5	12	22	35	51	70	92	117	145	176	210	247	287	330	376	425	477	532	590
6	1	6	**15**	28	45	66	91	120	153	190	231	276	325	378	435	496	561	630	703	780
7	1	7	18	34	55	81	112	148	189	235	286	342	403	469	540	616	697	783	874	970
8	1	8	21	40	65	96	133	176	225	280	341	408	481	560	645	736	833	936	1045	1160
9	1	9	24	46	75	111	154	204	261	325	396	474	559	651	750	856	969	1089	1216	1350
10	1	10	27	52	85	126	175	232	297	370	451	540	637	742	855	976	1105	1242	1387	1540
11	1	11	30	58	95	141	196	260	333	415	506	606	715	833	960	1096	1241	1395	1558	1730
12	1	12	33	64	105	156	217	288	369	460	561	672	793	924	1065	1216	1377	1548	1729	1920
13	1	13	**36**	70	115	171	238	316	405	505	616	738	871	1015	1170	1336	1513	1701	1900	2110

Figure 3. Modeling of polygonal numbers through a recursive definition (Relation 1)

For example, through visualizing polygonal numbers on the spreadsheet of Figure 3 students can discover that P(4,n) = P(3,n) + P(3,n-1), P(5,n) = P(3,n) + 2P(3,n-1), P(6,n) = P(3,n) + 3P(3,n-1), and then come up with the general conjecture

$$P(m,n) = P(3,n) + (m-3)P(3,n-1)$$

In other words mathematics visualization leads to discovery of Bachet's theorem:

Any polygonal number of side m is the sum of the triangular number of the same rank and m-3 triangular numbers of the previous rank.

Spreadsheet modeling can be used to validate Bachet's theorem through numerical evidence. The latter can also stimulate the development of proof by induction.

Students can use Algebra Xpresser to represent polygonal numbers algebraically. The important advantage of the Algebra Xpresser in comparison to other drawing applications is its ability to graph relations from any two-variable equations. This provides a nice opportunity to graph an equation without the need to convert the latter into a form suitable for "function grapher" software. So, setting x = n and y = m one can graph Relation 3 on the xy plane for any integer value of its left-hand side. This would make it possible to discover whether the graph passes through points with integral coordinates, and if so, every such a point would represent some polygonal number whose side and rank are just the coordinates of this point. The sketch shown in Figure 4 represents the use the Algebra Xpresser in modeling of the relation

$$\frac{x}{2}(x+1)(y-2) - (y-3)x = C \qquad (4)$$

on the "rank-side" plane for C = 6, 15, and 28.

The search of points with integral coordinates through which the curves pass results in the three pairs of points: (2,6) and (3,3), (3,6) and (5,3), (4,6) and (7,3). It is of interest not only to graph Relation 4 but also provide its interpretation. The latter can be as follows: hexagonal numbers 6, 15, and 28 are also triangular numbers. Is this true for all hexagonal numbers? Why or why not? This problem presents an excellent opportunity to explore connections among different polygonal numbers in a multiple-application environment.

Mathematics visualization of graphical representation of Relation 4 provokes many profound questions which may stimulate a discussion, conjecturing, and computer usage for justifying conjectures through visualization. For example, by changing the scale one may note that each graph has one and the same vertical asymptote x = 1. In other words, Relation 4 is not defined at the point x = 1, though the latter does have a sense in terms of polygonal numbers. What is the reason for that? Furthermore, each graph appears to have one and the same horizontal asymptote y = 2. How can this be explained in terms of polygonal numbers? Is it true for all polygonal numbers? Why or why not? Do these graphs have points in common with the asymptote y = 2? And if so, what are the x-intercepts of these points? Is it possible for two such graphs to have points in common? Given an integer C, does there exist an integral point on the related graph which also belongs to the bisector y = x? What is this point? Does there exist a polygonal number whose rank is two (three, four, etc.) times less than the number itself? Indeed, speculating on these questions fosters critical thinking, and develops skill in making connections among different representations of a concept.

Polygonal numbers can be generated by a spreadsheet through a Square Test. Modeling data are shown in Figure 5. New kind of representation makes it possible to visualize new patterns, to explore and discover new properties of polygonal numbers. For example, it is not hard to make the observation that there are pairs of

triangular numbers such that the sum of the numbers in each pair is a triangular number. The natural curiosity may raise the following questions:

How many such pairs can be found among triangular numbers?
Do the square numbers posses the same property?
Is it true for pentagonal numbers?
Does there exist any triple of triangular (square, pentagonal) numbers with the same property?
Is the product c´ two triangular numbers a triangular number?
Is the product of two triangular numbers a square number?

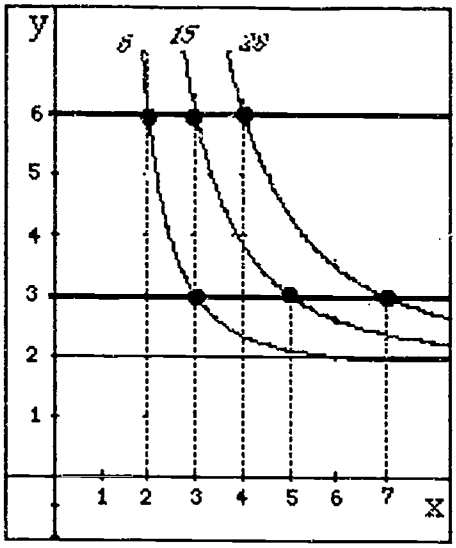

Figure 4. Graphical representation of polygonal numbers

	3	4	5	6	7	8	9	10	11	12	13	14
1	1	1	1	1	1	1	1	1	1	1	1	1
2												
3	3											
4		4										
5			5									
6	6			6								
7					7							
8						8						
9		9					9					
10	10							10				
11									11			
12			12							12		
13											13	
14												14
15	15			15								
16		16										
17												
18					18							
19												
20												
21	21					21						
22			22									
23												
24							24					
25		25										
26												
27								27				
28	28			28								

Figure 5. Modeling of polygonal numbers through the square test

We argue that the usage of a computer strongly promotes students' ability to discover many properties of integers. The teacher should convey his or her respect and admiration toward any new hypotheses that result from students curiosity and thereby boost students' awareness of themselves as doers of mathematics.

The curiosity of students can be highly motivated by the following demonstrations: numbers 21, 2211, 222111, 22221111, ... , as well as numbers 55, 5050, 500500, 50005000, ... , are triangular ; while numbers 5151, 501501, 50015001, 5000150001, ... , and 45, 4950, 499500, 49995000, ... , and 45, 2415, 224115, 22241115, ... are both triangular and hexagonal.

The important theorem that can be conjectured and validated through special cases is that *every natural number is 1) either a triangular number, the sum of two such numbers, or at most the sum of three triangular numbers; 2) either a square number, the sum of two such numbers, or at most the sum of four square numbers; 3) either a pentagonal number, the sum of two such numbers, or at most the sum of five pentagonal numbers; and in general, 4) either a polygonal number of side m, or the sum of at most m such numbers.*

In spite of the elementary statement of this theorem, first stated by Fermat, its proof requires more than elementary means (Ewell, 1992). The importance of technology in discovering and visualizing this theorem is very high.

Connection of polygonal numbers to primes

It is also possible to construct a learning environment which provides a dynamic visualization of how polygonal numbers relate to primes - a classical investigation in number theory. We suggest to implement on a single spreadsheet template both the Square Test for polygonal numbers and Eratosthenes' Sieve for primes. This allows study of frequency of primes among different polygonal numbers. As noted above, past use of

computers in such investigations required skills in programming languages. The replacement of the process of programming by the spreadsheet representation of integers with different properties is of a great importance to mathematics teaching - it gives students an opportunity to concentrate their attention on the subject matter rather than on unimportant details of syntax and semantics of the programming language. Moreover, the availability of dynamic media provided by a spreadsheet considerably enhances students ability to abstract from invariance. Actually, in order to discover invariance, to see what stays the same, one must have variation (Kaput, 1992). In such a way students can visualize and then conjecture that a prime exists between any two consecutive triangular or square numbers. The dynamic environment enables students to do explorations in number theory that may be beyond their teacher's knowledge. In this way mathematics classroom can be actually transformed into a laboratory, where the students and the teacher work as partners in exploring and discovering significant mathematical ideas.

References

Beiler, A.H. (1966). *Recreations in the Theory of Numbers*. New York: Dover Publications.

Ewell, J.A. (1992). On Sums of Triangular Numbers and Sums of Squares. *American Mathematical Monthly*, 99, 752-757.

Kaput, J. J. (1992). Technology and mathematics education. In D. A. Grouws (Ed.), pp.515-56. *Handbook of research on mathematics teaching and learning*. A project of N.C.T.M. New York: Macmillan.

Using Artificial Intelligence in the Teaching of Statistics

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Abstract: The teaching of statistics raises two important issues: how to handle a large amount of data on the one hand, and how to develop strategies using both quantitative and qualitative reasoning to analyze these data on the other hand. Computer-based learning systems can be used in the teaching of statistics. However, to be efficient, their instruction should be individualized. In other words, they ought to take into account each student's specificities. One approach that addresses this problem is to build a student model. Our student model QUARTS is described as a set of knowledge that evolves during the instruction. We use Artificial Intelligence techniques to represent the student model and dynamically update it during the instruction.

The teaching of statistics raises two important issues: how to handle a large amount of data on the one hand, and how to develop strategies using both qualitative and quantitative reasoning to analyze these data on the other hand. Because of their natural abilities to perform computations, computers have been used very widely in the field of statistics. Thus, many computer-based tools for statistics have been developed [Dambroise and Massotte, 1986]. They allow the student to avoid boring computations and to concentrate on the choice of appropriate problem solving procedures, and results interpretations. However, these systems are not *tutoring systems*, they can only be used as a complement of traditional instruction.

On the opposite, computer Aided Instruction (CAI) systems address the problem of *instruction*. The instruction of CAI systems for statistics is based on pedagogical hypothesis about the learning of statistics. In these environments, statistics tools are proposed to the student in order to facilitate data computation. However, although useful, CAI systems have proven limitations. An important one is that their instruction *does not vary* with the student that uses it. In fact, when a learner starts on a given course, he has personal knowledge and experiences that impacts on the way he will learn. Such individual knowledge is not taken into account by traditional CAI systems. In order to learn something new, we consider that it is important to have some means to relate it to earlier knowledge [Papert, 1991]. In this perspective, efficient systems should take into account individual student's knowledge so as to suggest student appropriate means to learn new concepts [Clancey and Soloway, 1990].

Individualizing instruction using a student model

In real life, a teacher does adapt his/her teaching to different students because different students need different pedagogical approaches. To do so, the teacher may use a mental representation of students' specificities,

i.e. their knowledge and/or the way they reason, their preconceptions, misconceptions, etc. One way to make a computer system adapt its teaching is to provide it with a model to represent and manipulate knowledge about students. Such knowledge is often embedded in a model called *the student model*. The student model allows the system to use different pedagogical course for different types of student. In other words, it means that the curriculum is not identical for every student, but dynamically built depending on the student's profile. Tutoring systems that possess such a model are known as Intelligent CAI (ICAI) systems. To build student models, which involves representing human resolution processes, Artificial Intelligence (AI) techniques have been widely used [Mizoguchi, 1991]. They address the modelization of different aspects of student knowledge and reasoning.

In the next section, we present the kind of knowledge that we consider to be necessary in a student model for the teaching of elementary descriptive statistics.

What kind of student model ?

In our multidisciplinary research team, we see the teaching of statistics as the teaching of a process which takes the student from raw data to the elaboration of conclusion using strategies and reasoning. One goal of teaching descriptive statistics is to make the student acquire problem solving strategies using both qualitative and quantitative reasoning to analyze the data. Our hypothesis is that an efficient teaching of statistics using computers should be based on a deep understanding of the kind of knowledge and reasoning used by the student [Rouanet et al., 1987].

Our studies on the teaching of elementary descriptive statistics [Corroyer et al., 1988] have lead us to consider two key aspects that should be supported by a student model. The first one is the ability to represent both qualitative and quantitative knowledge as well as their associated reasonings and problem solving heuristics. The second one is the ability to represent student's possible misconceptions and non-monotonic reasonings; e.g. a student being able to calculate the weighted average of his exams notes, but unable to calculate the weighted average of bananas' length.

Regarding the use of the model, we see the student model as a set of knowledge that should evolve during the instruction. The student model is only significant for the system to individualize instruction if it reflects the dynamic evolution of the student's knowledge. Using AI techniques, such evolution of the student's knowledge may partially reflects human acquisition processes.

The QUARTS student model

In order to represent the student's knowledge key aspects (see section above), we use in our student model called QUARTS two AI approaches:*Problem Solving Principles* and *Theory Revision*. We have adapted *Problem Solving* to problems where qualitative and quantitative reasonings are needed [Williams and de Kleer, 1991]. To represent the dynamic evolution of such knowledge, we have decided to adapt *Theory revision* [Adé et al., 1994] to theories where both qualitative and quantitative information are used. QUARTS' four main components are sketched on figure 1 hereafter.

The three first components are described in the next section, whereas the fourth one is explained in a following section.

An AI based model to represent the student's theory

The *student's theory* is composed of problem solving knowledge, domain knowledge and a resolution module. This theory reflects the way the student uses knowledge and solves problem. The student's theory contains all information needed by the system to individualize its instruction.

General problem solving knowledge

Our work is based on the hypothesis that to build a strategy to solve a problem, a student uses problem solving knowledge that is independent of the domain of instruction. In other words, we want to introduce in our model some general common sense that is dedicated to problem solving. To do so, we break down problem solving knowledge into three types of knowledge:

- **Elementary Operation** (ELO).This is a problem solving potential action (e.g.*Characterize data*). An ELO is instantiated in a concrete domain with one domain operator (e.g.*Determine the average* on *the two data sets*). Each ELO may be instantiated by more than one domain operator. Heuristic

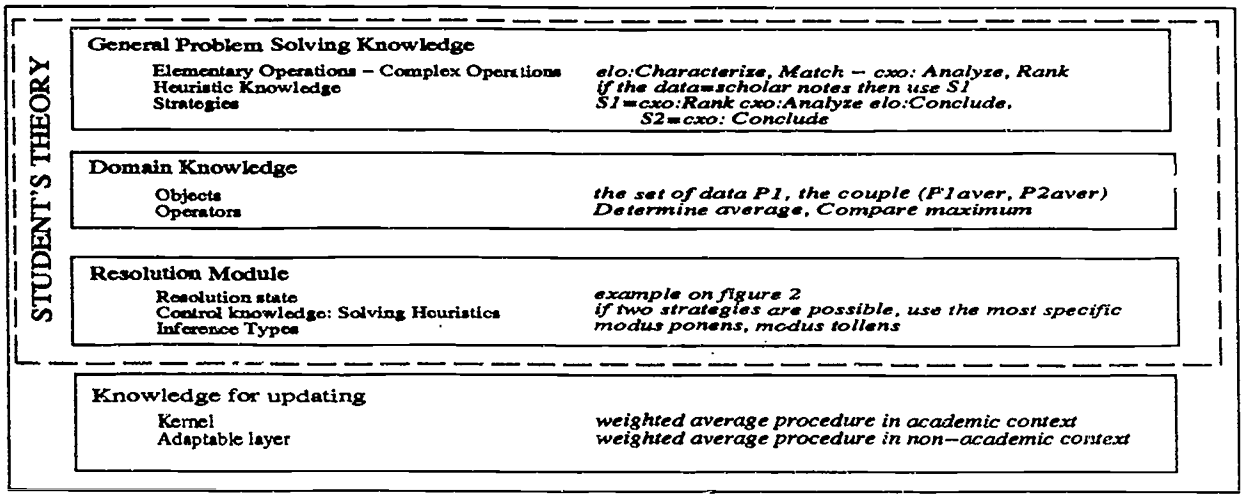

Figure 1: The four components of QUARTS *(Examples of sub-components are in italics)*

knowledge associated with an ELO is used to choose the domain operator and its parameters to perform the elementary operation.

- **Complex Operation** (CXO).This is an operation which is decomposed into both elementary and complex operations. The instantiation of a CXO in a concrete domain is a sequence of domain operators. Heuristic knowledge associated with a CXO is used to choose a strategy to solve the complex operation considered, depending on the resolution state of the problem (cf. figure 2). As an example, to solve the complex operation *Analyze the data*, the strategy *S=Characterize data, Compare judgements* can be chosen.

- **Strategies**.They determine the problem solving stages. Each strategy corresponds to a list of elementary and complex operations to solve the problem. The strategies are predefinite and associated with the complex operation they are supposed to solve. An example of strategy to solve the problem of *Comparing sets of numbers* can be *S=Rank the data, Analyze the data, Conclude.*

The domain knowledge

The domain knowledge is used to modelize specific knowledge of the instruction field. In our case, it corresponds to elementary descriptive statistics knowledge. The domain knowledge is mainly represented by operators and objects.

- **Operators.** These are domain related potential actions used to solve an elementary operation. An example of operator to solve the ELO *Characterize data* could be *Determine the average, Determine the maximum.*

- **Objects.** The objects are the parameters of the domain operators. Examples of objects are *the two sets of data, one set of data, a subset of data, etc.*

Resolution Module

The resolution module modelizes the student's reasoning. The resolution module manipulates a *resolution state* that contains the problem description, different objects created during the solving process and the strategy used to solve the problem. The resolution module modifies the resolution state (see figure 2) using different kinds of student's inferences and problem solving heuristics, until conclusions do satisfy a criteria that measures the conclusions' quality. Figure 2 shows an example of a final resolution state on a very simple problem. The problem's data are the two sets P1 and P2. To solve the problem, the resolution module has chosen the strategy CXO:*Rank* CXO:*Analyze* CXO:*Conclude.* It has already chosen strategies to solve complex operations, and applied some domain operators to solve elementary operations. The current operation is the complex operation CXO:*Conclude.*

Objects	Judgements	Conclusions	Strategy
P1={7,3,9,5} P2={4,8,4,1} P1Rank={3,5,7,9} P2Rank={1,4,4,8} P1aver = 6 P2aver= 4.25 (P1aver, P2aver)	P1aver: good, P2aver: bad	P1aver is better than P2aver	CXO:Solving the problem (CXO:Rank CXO:Analyze (ELO:Characterize ELO:Match ELO:Compare) $\boxed{\text{ELO:Conclude)}}$

Figure 2: Example of a resolution state where the current operation is set to *Conclude*

Acquiring and updating the model

We describe in this section how the model is acquired and focus on the model's component dedicated to revision. Then we present the general principles of the automated updating process.

Acquiring

Two research teams cooperate to acquire the student model within this representation knowledge framework: one composed of AI researchers, and one composed of Statistics teachers. The domain is "descriptive statistics taught to first-year undergraduate students". The statisticians team is mainly concerned with the students' processes and pre- and mis-conceptions in the domain of descriptive statistics. In fact, any student has already used, consciously or not, statistical notions, even before he is explicitly taught statistics. For example, most student frequently analyze their exams notes. When a student, who has never learned statistics, is asked to analyze some numerical data, the procedures he will use are most likely to be related to statistical ones. We call *natural processes* these processes that exist before an explicit learning of statistics [Corroyer et al., 1988]. We claim that, before the instruction starts, the student's model must contain an initial student's prototype. A student's theory which can be shared by several students is referred as a *prototype of student's theory*. So far, we have identified three prototypes of theory for beginners: one for students who mostly manipulate qualitative knowledge and make qualitative reasonings, one for students who mostly use quantitative knowledge and make quantitative reasonings, and one for students who mostly use quantitative knowledge and make quantitative or qualitative reasonings.

When a student starts the instruction, the system associates him with one of the three pre-defined prototype student model. This initialized student model has then to be adapted to the student. The principles of adapting a prototype to a real student are identical to the one used to update the model during the instruction. Before explaining these revision principles, we describe QUARTS' component that has been defined for controlling the model's updating.

The Knowledge for Updating

The *Knowledge for Updating (KU)* is considered as representing the potentially acceptable evolution of a student model initialized with a pre-defined prototype. The KU is represented with two components: a *kernel*, corresponding to knowledge that is a priori indispensable, and an *adaptable layer* corresponding to knowledge that can be revised. Both components are a set of links on knowledge of the *student's theory*, i.e. domain knowledge, objects, heuristic knowledge.

To clarify the notion of kernel and adaptable layer, let us give a concrete example. The typical student we are interested in is first-year undergraduate. He has often calculated a weighted average of notes, in an academic context. Thus, we set the *"weighted average procedure in an academic context"* as part of the kernel of a student model prototype. It means that this knowledge is indispensable. Every student who has been associated to this prototype is considered as having this knowledge. On the opposite, the *"weighted average procedure in another context"*, belong to the adaptable layer. It means that the system supposes that the student has this knowledge, but such belief can be revised if appears later that the student does not have this knowledge.

If we consider two students that have been associated with the same initial prototype, their student model's kernel is exactly the same, but the content of their adaptable layer may be different.

Updating the model: a form of revision

During the instruction, new information about the student is made available for the model to be updated. To integrate this new information, the system revises the content of the student model. A revision consists in modifying the current model or re-initializing the model with another pre-defined prototype. Modifying the current model consists in adding new knowledge into the adaptable layer, or modifying or deleting an existing knowledge of the adaptable layer. However, if the new information is inconsistent with the student model kernel, for example if it contradicts a kernel information, modifying the current model is impossible. The prototype used at the initialization is then considered to be inappropriate for the student, and another one has to be chosen. Thus, updating the model consists in changing the student model adaptable layer, enriching its content, or, if it becomes necessary, choosing a more appropriate kernel.

Conclusion

Computer-based statistics instruction can be improved by the use of student models. There already exists ICAI systems in statistics such as PROSAIC [Terral, 1990], but we consider that their student model is not suited for the kind of teaching we want to provide. We believe that ICAI systems in statistics should teach problem solving strategy and reasoning on both qualitative and quantitative knowledge. We propose a general student model integrating both qualitative and quantitative information. We have adapted AI techniques, namely *Theory revision* and *Multi representation Problem Solving* to respectively represent the model and update it. We have briefly presented how this model could be used in the field of elementary descriptive statistics. QUARTS is currently under implementation and we plan to evaluate it in a classroom before integrating it into a tutoring system.

References

[Adé et al., 1994] Adé, H., Malfait, B., and Raedt, L. D. (1994). RUTH: an ILP Theory Revision System. In *ECML/MLNet: Workshop on Theory Revision and Restructuring in Machine Learning*, Catania, Italy.

[Clancey and Soloway, 1990] Clancey, W. and Soloway, E. (1990). Artificial Intelligence and Learning Environments: Preface. In *Artificial Intelligence 42*. North-Holland.

[Corroyer et al., 1988] Corroyer, D., Rouanet, H., Guigues, J., and Mathieu, J. (1988). Utilisation de l'outil informatique dans l'enseignement d'un champ conceptuel particulier: les premières notions de statistiques. Technical report, Rapport de fin de contrat du Ministère de la Recherche et de l'Enseignement Superieur,n86J0019, Paris.

[Dambroise and Massotte, 1986] Dambroise, E. and Massotte, P. (1986). MUSE: An expert system in statistics. In *Compstat*.

[Mizoguchi, 1991] Mizoguchi, R. (1991). Student Modelling in ITS. In *Proceedings of the International Conference of Computers in Education - Tutorials*, Taiwan.

[Papert, 1991] Papert, S. (1991). Situating constructionism. In Harel, I. and Papert, S., editors, *Constructionism*, pages 1–12. Arlex Publishing Corporation Norwood, New-Jersey.

[Rouanet et al., 1987] Rouanet, H., Roux, B. L., and Bert, M. (1987). *Statistique en Sciences Humaines: Procédures naturelles*. Dunod, Paris.

[Terral, 1990] Terral, S. (1990). PROSAIC: un enseignement par la résolution de problèmes. In *Actes des journées internationales sur les systèmes experts et leurs applications*, Avignon.

[Williams and de Kleer, 1991] Williams, B. and de Kleer, J. (1991). Qualitative reasoning about physical systems: a return to roots. In *Artificial Intelligence - vol 51*, pages 1–10.

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Computer-Assisted Tutorials for At-Risk Students of Mathematics: Lessons Learned from a Canadian Pilot Project.

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Abstract: Serious problems exist in mathematics achievement in Canada. In response to this problem, we conducted a four month remedial tutorial program for at-risk students of mathematics who attended Grades 9 - 12 in the Canadian Province of Newfoundland and Labrador. In both tutorial groups, each at-risk student received individual attention from a qualified instructor. In the computer-assisted (CAI) tutorial groups, this personalized instruction was supplemented by access to computer software designed to teach mathematics.

In this paper, we focus on the CAI tutorial groups. We describe practical suggestions for improving CAI in this kind of tutorial setting based on careful observations and acutal problems experienced during the project. We discuss suggestions for the preparations of CAI tutorials, for the implementation of CAI tutorials, and for evaluating the success of CAI tutorials. This discussion will include instructor, students, and curriculum-related considerations. Finally, the need for follow-up instruction is discussed.

Introduction to the Tutorials in Math Project

General Background

Serious problems exist in mathematics education and achievement in Canada (Government of Newfoundland and Labrador, 1989; 1992; 1993; Spain and Sharpe, 1990). In response to this problem we conducted a four-month tutorial program for at-risk Grade 9-12 mathematics students in the Canadian Province of Newfoundland and Labrador. The remedial tutorials were carried out two evenings a week (three hours per evening) outside of school hours.

In an attempt to establish baseline data for students participating and to determine if these were indeed at-risk, during the first night of the program each was asked to write the Mathematics skill section of CTBS (Can dian Test of Basic Skills) appropriate to each student's grade level. These tests are regularly used by the province to measure the skill level of Newfoundland students compared with norms set by those nationally standardized tests. The average range lies between the 40th and the 60th percentile. Students in Newfoundland and Labrador score at the lower end of the average range; i.e., at the 40th percentile (Government of Newfoundland and Labrador, 1992, 31). The CTBS average for students on the **Tutorials in Math Project** was at the 24th percentile, which made these standards very much at risk.

In December 1992, we were asked to develop a remedial tutuorial program for at-risk students of Mathematics by the Canadian Employment and Immigration Centre's "Stay in Schools" initiative. The project began in January of 1993 with very little lead-time and it was completed in June 1993. Students were randomly assigned to one of two types of tutorials: three standard or traditional small tutorial groups and three small tutorial groups with access to CAI. Each student received six hours of instruction per week. All six of the instructors hired had backgrounds in mathematics instruction; three were assigned to the standard tutorial groups and three to the tutorial groups with computer assistance. Students in the three standard groups were instructed in separate classrooms while the three groups with access to CAI were instructed in a computer room with additional classroom seating space.

The Students

Forty-eight students were selected from eleven schools to participate in the project: 24 were assigned to the standard groups and 24 were assigned to the computer assisted instructional groups. Candidates were recommended mainly by their classroom Mathematics teachers. Students were selected as follows: 12 grade nine, 12 grade ten, 12 grade eleven, and 12 grade twelve. Most students were currently enroled in an academic, or mid-range of difficulty, Mathematics program. There were no special education students in the program.

Preparation of CAI Tutorials

Adequate preparation for a CAI tutorial should include a comprehensive review of the relevant literature related to CAI and how best to instruct using CAI (Barnes, 1991; Bennett, 1991; Dalton, Hannafin & Hopper, 1989; Kulik and Kulik, 1989; Mackie, 1992). A review of literature related to the characteristics of the learners (at-risk students of mathematics in our case) is also useful (Bosch and Bowers, 1992; Sagor, 1988; Vatter, 1992).

Candidate software must be identified and tested and the actual software that will be used must be selected and obtained. We recommend that the chosen software match the school curriculum and be suited to the learners' abilities. Efforts were made to identify and choose appropriate software using printed catalogues, electronic searches, requests on the Internet, and personal sources. Difficulties were also encountered in identifying appropriate software and then in obtaining that software. We have concluded that the importance of obtaining suitable software, and the difficulties encountered, cannot be underestimated.

Preparation should include adequate time for substantial in-service training to thoroughly familiarize the tutorial instructors with the selected software. The assumption that computer-experienced instructors know how to instruct effectively using CAI should be carefully examined. It may be necessary to provide instructors with training in how to teach effectively using CAI.

In summary, we have concluded that substantial "lead time" (at least 10 weeks) is necessary for adequate preparation of a CAI project.

Implementing CAI Tutorials

Our pilot study included careful observation of instructors and students during actual CAI instruction. Observations were made nightly of the tutorial sessions; these sessions yielded data which form the basis of a descriptive profile of the at-risk Mathematics student. Four students were also identified for closer study. Regular meetings of the research team were conducted to plan and report monitoring observations and to make adjustments. Extensive interviews were conducted mainly by researcher with project team members, students, instructors, and classroom teachers.

Several important lessons were learned. Instructors may make the faulty assumption that the CAI package can teach students independently, requiring little or no intervention on the instructors' part. Such was certainly not the case for our at-risk students. These students appeared to pay little attention to the verbal instruction offered by the CAI packages. This could be partly attributed to poor reading skills in at-risk students of mathematics. The results of the standardized Canadian Test of Basic Skills (CTBS) reading scale indicated that our at-risk students should be carefully and thoroughly instructed in how to use a particular CAI package. At-risk students should also be carefully guided and monitored by their instructors while using CAI packages.

Other observations indicated the inadvisability of mixing students from different grade levels in a single CAI tutorial group; formation of several small tutorial groups with students from the same grade level kept together may be more effective. We also observed that students spent less time than anticipated with the CAI packages perhaps because of a poor match with the curriculum. Finally, our observations suggest that tutorial sessions should be fairly brief (an hour maximum) with at-risk students.

Evaluating the Success of CAI

We used a variety of methods to try to determine the success of both the CAI and standard tutorials.

These included the use of standarized tests (CTBS), questionnaire measures of students' attitudes toward mathematics, observations during actual tutorial instruction, in-depth interviews of students and their regular classroom teachers, and final grades.

We have more or less abandoned a "pure", scientific comparison of the two tutorial groups (standard plus CAI versus standard tutorial instruction) partly because different instructional events transpired in the two groups. Such a comparison is always fraught with various difficulties unless a very tightly controlled study can be conducted which is rarely possible. Interviews with CAI students indicated that they believed that they were deriving significant benefits from the tutorials generally but not specifically from the CAI. One change that was evident in both interviews with many students and with their regular classroom teachers was an improved attitude and increased confidence towards mathematics. Final grades indicated some improvement in both standard and CAI groups.

We would recommend collection of a variety of measures from a variety of sources to assess the success of CAI. We suggest measuring the effects of CAI on student attitudes as well as on performance. Finally, one should be aware that the effects of CAI (or of any instruction) may be delayed rather than immediate. We intend to follow our students as they proceed through high school to chart their progress.

Follow-up Instruction

Many research projects have fixed funding and a limited duration. Our students were given four months of tutorial instruction but were then on their own. Clearly, there may be a need for continuing remedial instruction, but there is the question of who will provide this? This problem, common to many research projects, will be discussed.

References

Barnes, J.M. (1991) Mathematics CAI in the classroom. **Math Council Alberta**, 30(1), 23-28.

Bennett, P.J. (1991) Effectiveness of the computer in the teaching of secondary school mathematics: Fifteen years of reviews of Research. **Educational Technology**, August, 44-48.

Bosch, K.A., & Bowers, R.S. (November/December, 1992). "Count Me In, Too". Math instructional strategies for the discouraged learner. **Clearing House**, 104-106.

Dalton, D.W., Hannafin, M.J., & Hooper, S. (1989). The effects of individual versus cooperative computer assisted instruction on student performance and attitudes. **Educational Technology Research and Development**, 37(2), 15-24.

Government of Newfoundland and Labrador, 1989. **Towards An Achieving Society**. Task Force on Mathematics and Science Education Final Report.

Government of Newfoundland and Labrador, 1992. **Profile '92, Educational Indicators**, Department of Education.

Government of Newfoundland and Labrador, 1993. **Our Children Our Future**. Royal Commission on Education Final Report.

Kulik, J.A. and Kulik, C.C. (1989) Effectiveness of Computer-Based Instruction. **School Library Media Quarterly**, 17(3) 156-159.

Mackie, D.M. (1992) An evaluation of computer-assisted learning in mathematics. **International Journal of Mathematical Education in Science Technology**, 23(5), 731-737.

Sagor, R. (1988) Discouraged Learners Teetering on the Edge of Failure. **Learning**, April: 29-34.

Spain, W.H. and D.B. Sharpe. (1980). **YTLM Youth Transition Into the Labour Market**, Center for Research and Development, Memorial University of Newfoundland.

Vatter, T. (1992) Teaching Mathematics to the At-Risk Secondary School Student. **The Mathematics Teacher**, 85(4), 292-294.

22

Microworlds and Situated Learning in a Primary Classroom

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Abstract: It has been argued that computer microworlds may offer a fertile soil for implementing a situated learning environment in the classroom. In this paper we report on a project in which a mathematical, 'pre-Logo' microworld, previously developed by the author, was implemented in a primary classroom over a period of several months. First, the Microworld environment with the associated learning materials and implementation strategies is described. Classroom observations are then reported, demonstrating that the microworld, coupled with the appropriate instructional intervention, enabled the development of a learning environment and classroom culture in accordance with the principles of cognitive apprenticeship and situated learning.

Introduction

Recently, the topic of situated cognition has received a great deal of attention from educational researchers. Brown, Collins and Duguid (1989) have suggested that learning should take place in the context of realistic settings; by engaging in "authentic tasks", students immerse themselves in the culture of an academic domain. Concern with the situatedness of learning spans all aspects of the instructional process, from lesson planning to the assessment of outcomes (Steibel, 1989; Young, 1993). Situated learning is closely related to the concept of 'cognitive apprenticeship', as described by Collins, Brown & Newman (1989). Cognitive apprenticeship methods try to enculturate students into authentic practices through activity and social interaction in a way similar to that evident in craft apprenticeship.

It has been argued that computer microworlds (Papert, 1980) and similar technology-enhanced learning environments may offer appropriate tools for implementing situated learning in the classroom (e.g. Collins, Brown & Newman, 1989; Cognition and Technology Group at Vanderbilt; 1990). Particularly, students working with computer microworlds are exposed to concepts and skills in a problem-solving context where their functions are instrumental to the accomplishment of meaningful, authentic tasks. (Damarin, 1993).

In this paper we report on a study in which a mathematical, 'pre-Logo', microworld, previously developed by the author (Cohen & Geva, 1989; Cohen, 1990) was implemented in a primary classroom over a period of several months. As will be shown below, the resulting learning environment and classroom culture could be considered to be a primary classroom implementation of a cognitive apprenticeship environment.

The Microworld Learning Environment

The Macintosh-based Microworld used in this study was the second in a graduated series of four microworlds previously designed by the author (Cohen & Geva, 1989; Cohen, 1990). The Microworld consists of an open-ended computer environment including a set of commands which can be used to order the turtle to move or draw within a bordered graphics screen, referred to as the "Turtle's room". To encourage use of measurement, the graphic screen borders, or "walls", are marked as rulers with visible units of distance. (see Fig. 1). One unit along the border corresponds to one "turtle step". If the Turtle is given a command that would cause it to move or draw beyond the screen boundaries, an appropriate error message such as "I will hit the floor if I do this" (or ceiling, wall, etc.) appears on the screen.

Unlike the turtle geometry microworld in Logo, in this Microworld an absolute frame of reference is used, namely, the Turtle always faces the top of the screen, and can only move up, down or sideways with respect to the screen boundaries, without changing its heading. Commands can be given to the turtle to make it move Up, Down, Right or Left on the screen a specified number of units, with or without dragging the pen. The commands include the Draw commands: DU, DD, DR and DL (Draw Up, Down, Right and Left), or the Jump

commands: JU, JD, JR and JL (Jump Up, Down, etc.). Three ready-made shapes, a Square(SQ), a Circle(C) and a Triangle(T), are also available, filled with a pattern or outline only. Numeric inputs are used with each of these commands. For instance, the command DR 5 causes the Turtle to draw a line to the right 5 units long, SQ 3 (T 3) causes it to draw a square (triangle) with side length 3 (base and Height length 3), and C 4 causes the Turtle to draw a circle with a diameter 4 units long. Several commands can be chunked on one line, if desired.

The Macintosh-based Microworld includes a menu-driven user interface, especially designed for young school children. Features of the interface include an on-line HELP utility, illustrating all basic microworld commands and features, a TOOLS menu, offering on-line measurement tools such as horizontal and vertical ruler, and a grid. The grid is meant to facilitate the child's understanding of two dimensional coordinates, while the ruler utility enables the child to "grab" the ruler and move it across the screen to the desired location. Additional features include highlighting of errors in command lines, along with specific error messages (e.g. "I will hit the wall if I do this", "I don't understand JRR" or "I need a number after DR") and an UNDO command which cancels the effects of the last command line entered (see Figure 1 below).

A recording facility is also included, which records, along with every command line issued by the child, also every error made and every use made of the HELP menu or of the measurement tools. The child's actions can later be "replayed" fast, movie style, or line-by-line, where each command line, along with its graphic effects, can be examined. Such a utility has the potential to assist the students in reviewing their work, planning and improving strategies, as well as in sharing not only their final product but also their processes.

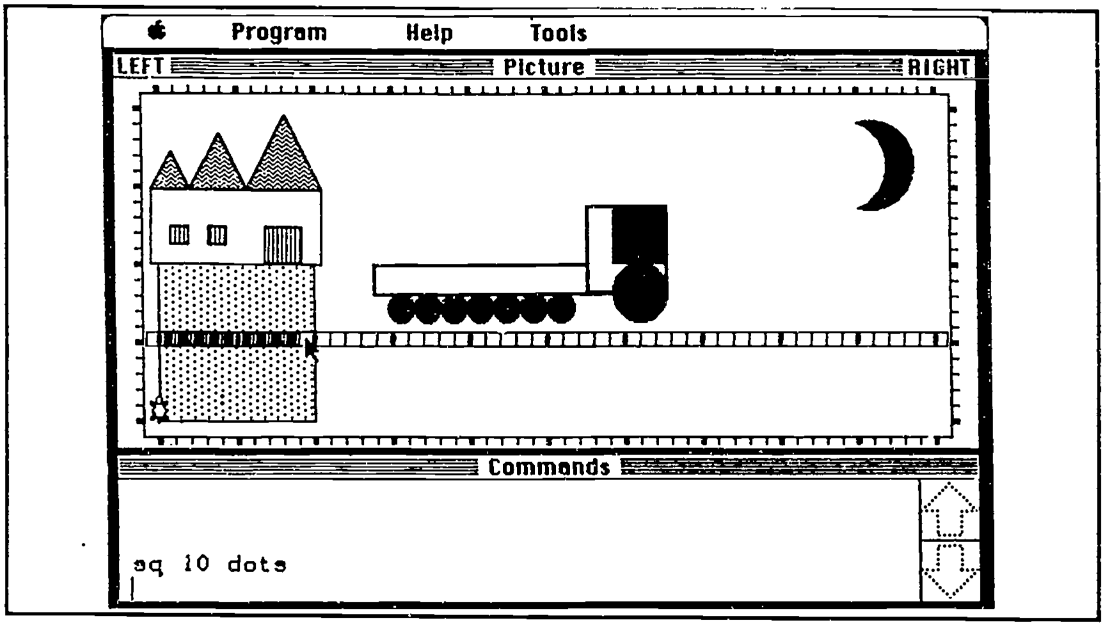

Figure 1. A typical Microworld screen with the on-line ruler

Classroom Implementation and Methodology

Microworld was implemented in a combined grade 2-3 classroom equipped with 3 Macintosh computers over a five month period. Computer practice was a regularly scheduled component of classroom activities and was monitored by the classroom teacher. Each student spent an average of 3 25-30-minute sessions per week working on the computer. Initially, all students worked with a partner, but later on, some of them preferred to work individually and were allowed to do that.

Much of the students' activity within the Microworlds was devoted to exploration and pursuit of self-defined goals. To encourage the children to preplan their computer work, they were supplied with "planning sheets" which consisted of a paper version of the bordered screen, often with a grid background, on which to plan their graphic designs.

Five collections of structured computer tasks, referred to as **challenges**, were supplied to the teacher with the Microworld software. A typical challenge involves asking the student to produce, on the right side of a divided screen, an exact replica of a drawing presented on the left side. In some challenges, the right side of

the screen is initially empty. In others, it may have an incomplete reproduction of the drawing on the left side, and the student is asked to complete the drawing on the right so as to make it identical to that on the left . In still other types of challenges, the child is asked to continue a repeating pattern (see Figure 2 below).

These challenges were devised by the researchers as a means of ensuring exposure to specific concepts, skills or strategies, as well as for evaluating a child's progress within a Microworld. The challenge collections were organized in increasing level of complexity.

The Microworld software also included an easy-to-use challenge creation utility. This utility was often utilized not only by the teacher, in designing learning materials, but also by the students, who liked to create challenges for each other, and also for the teacher and researcher.

Classroom observations were conducted by research staff 1-2 times per week for a two hour period. The researchers acted as participant observers, usually not initiating activities or discussion but rather responding to students' questions or requests for help. Sometimes, however, the researchers would provide students with specific challenges in order to assess their progress. Detailed protocols of children's work on the challenges were automatically recorded on the computer. Informal teacher and student interviews were also conducted throughout the study period.

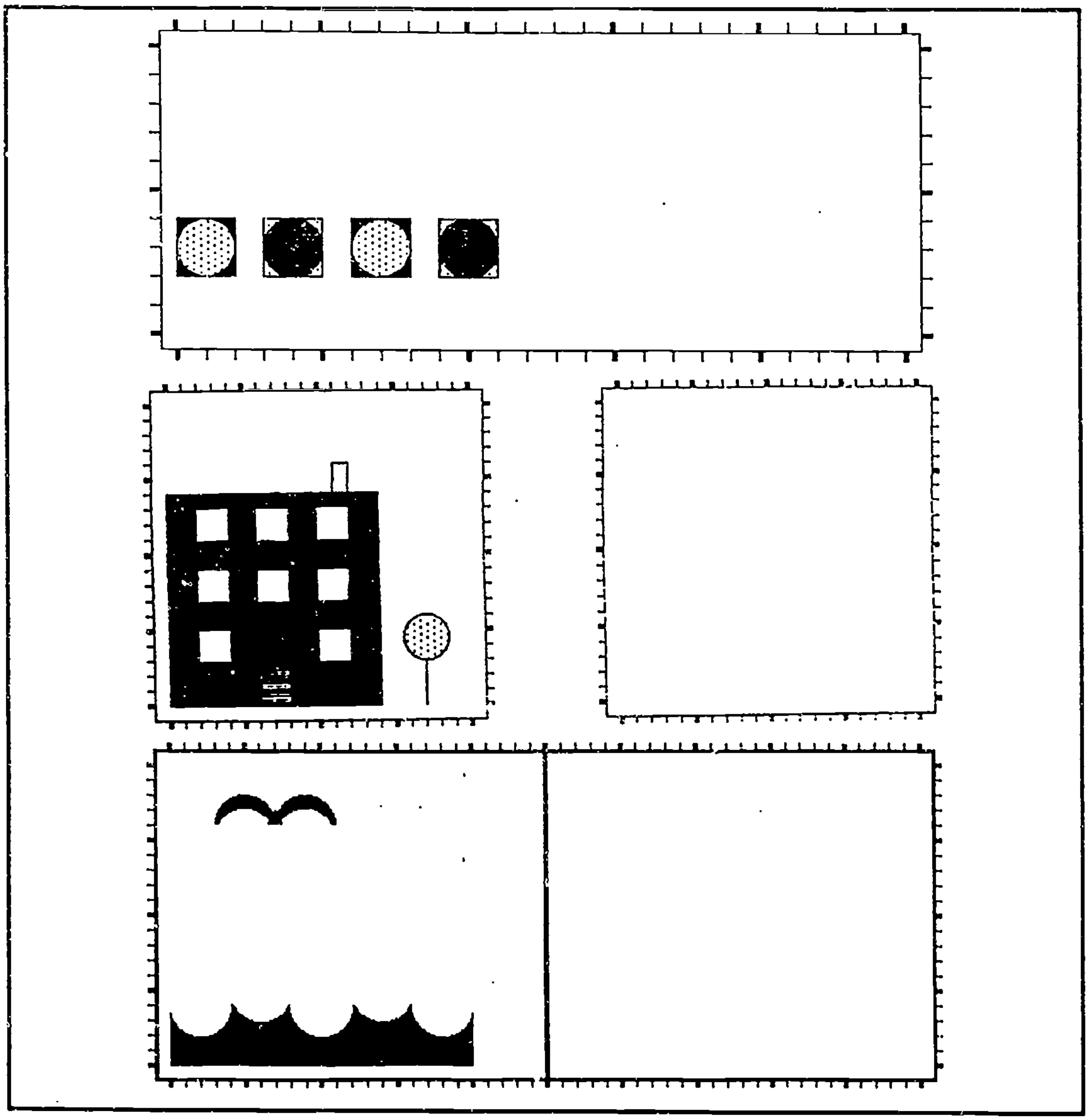

Figure 2. Examples of challenges.

Findings and Discussion

Classroom observations indicated that the Microworld, coupled with the specific instructional intervention, provided a fertile soil for the development of a learning environment and a classroom culture in accordance with the principles of cognitive apprenticeship and situated learning. In what follows, we will describe the learning environment and classroom culture, as observed in this study. It will be shown that such a learning environment possesses nearly all of the characteristics included in the *Framework for Designing Learning Environments*, suggested by Collins & al. (1989, pp. 466-491) in their paper on cognitive apprenticeship. In what follows, we will be referring to the above Framework.

Content: The content learned within the Microworld environment includes domain knowledge, namely, specific mathematical-spatial concepts, as well as the heuristic strategies , control strategies and learning strategies developed by the students while exploring the Microworld, working on projects or solving challenges.

Sequence: The teacher introduced the Microworld concepts and skills in a sequence dictated by level of difficulty. The learning activities were presented in order of *increasing complexity*, where more and more of the skills and concepts necessary for expert performance were required. Specifically, the challenge collections included in the Microworld software package covered different topics and were organized by increasing complexity, and also in *increasing diversity*. Each challenge collection was organized according to increasing difficulty level. Furthermore, in contrast with the Logo language, the Microworld provided the students with ready-made shapes and tools, so that even 6-7 year old children could produce pleasing and meaningful designs or 'pictures'. These students were relieved of having to carry out lower level or composite sub-tasks in which they lacked skills, and were able to build a conceptual map of the whole process, while being exposed only to the global skills. So this 'pre-Logo' Microworld was designed according to the principle of *global before local skills*, with the intention that the students might later on be introduced to subsequent, more complex, microworlds, or to the full blown Logo language. (As indicated above, this Micro world was the second in a graduated series of four microworlds previously designed by the author. These Microworlds or task environments were also organized in order of increasing complexity.)

Teaching Methods: The teacher, who was the domain expert or 'master', played a central role in supporting the students' learning. While the learning philosophy associated with microworlds strongly favours experiential discovery and learner control, the students needed access to practical and theoretical support, assistance and guidance, particularly in the initial stages of acquiring the new knowledge. As was mentioned above, the computer environment itself provided a variety of learner support and scaffolding features; specifically, the HELP screens, the friendly user interface that was tailored to young children, the on-line measurement tools and the recording utility.

Yet, the computerized support features did not replace the teacher, who continually monitored student activity through guiding, coaching, scaffolding, providing valuable feedback and modelling problem solving processes. The teacher's support in technical and procedural matters faded over time as the young learners assumed greater ownership of the knowledge and processes involved. However, the teacher continued to be actively involved in the learning process. She encouraged her students to reflect on their learning by observing their own, as well as their peers', problem solving processes using the REPLAY feature, trying alternative solution processes and evaluating them with their classmates.

Sociology: The classroom culture was certainly the culture of expert practice, where the participants actively communicated about and engaged in the skills involved in expertise. The teacher continually stimulated her students by suggesting meaningful project ideas, initiating class or small group discussions and linking the Microworld work with other classroom activities, topics and projects. The teacher and the researchers designed on-line and off-line learning units and materials related to specific themes in Social Studies or Science. In Mathematics, for instance, activities with manipulative materials related to patterning, place value arithmetic, geometric shapes and measurement were closely linked with teacher-designed Microworld activities. Another unit related to map reading, called 'Adventures of the Country Turtle who Travels to the City', was linked with other Environmental Studies activities. Other examples of linking the Microworld work with classroom activities were related to story writing, nutrition, and the Pioneers. Thus the learning activities were situated in meaningful and varied contexts.

Microworld related activity was often the topic of discussion in this classroom. While working on the teacher/researcher designed structured activities, students also continued to engage in free exploration and creative enterprises, both individually and in pairs. They particularly enjoyed constructing difficult challenges for each other, or for the teacher and researchers, utilizing the challenge creation utility. The most difficult challenges were often given to the teacher (or researcher) to solve in front of the class, or a group of students,

thus exposing the students to the expert's problem solving processes. Some of these challenges, created by some persevering students through repeated, and clever use of overlapping colored shapes, in combination with the Erase feature (which whites out a whole area), were indeed challenging even for the teacher and researchers (e.g. see the third example in Figure 2 above). Activities such as the ones described above often involved an element of competition, while they also usually involved cooperation among students.

Conclusion

The classroom environment described above shares many of the characteristics of a cognitive apprenticeship and situated learning environment. It should be pointed out that while the Microworld software and materials were indeed essential for such an environment, it was the classroom teacher who played the central role in creating the learning environment and classroom culture that accompanied the Microworld activity. Through providing appropriate guidance and support, stimulating her students to engage in Microworld-related problem solving, reflection and discussion, encouraging group work, acting as the class 'expert' while modelling her own solution processes to student-generated challenges, creatively linking the Microworld work with other classroom topics and activities, this teacher helped create a cognitive apprenticeship environment and learning culture in her classroom. For the students within this culture, Microworld related activities were indeed authentic.

References

Brown, J. , Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher*, 18(1), 32-42.

Cohen, R., and Geva, E. (1989a). Designing Logo-like environments for young children: The interaction between theory and practice. *Journal of Educational Computing Research*, 5(3), 349-377.

Cohen, R. (1990). Computerized learner supports in pre-Logo programming environments. *J. for Research on Computing in Education*, 22(3), 310-335.

Collins, A., Brown, J. & Newman, S. (1989). Cognitive apprenticeship: Teaching the crafts of reading, writing, and mathematics. In *Knowing, Learning, and Instruction: Essays in Honour of Robert Glaser.* Edited by L. Resnick, Lawrence Erlbaum Associates: New Jersey.

Damarin, S.K. (1993). Schooling and situated knowledge. Travel or tourism? *Educational Technology*, 33(3), 27-32.

Papert, S. (1980). *Mindstorms*. New York: Basic Books.

Steibel, M. J. (1989). Instructional plans and situated learning. *Journal of Visual Literacy*, 9(2).

Young, M. F. (1993). Instructional design for situated learning. *Educational Technology Research and Development*, 41(1), 43-58.

Technology in the Teaching and Learning of First Year Algebra

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Abstract: Graphing capabilities of calculators and computers now make it possible for first year algebra students to explore visual representations of abstract concepts. With spreadsheets, students can observe patterns then generate formulas, and graphs for these patterns. By graphing linear applications with calculators, students visualize slope as a rate of change. Quadratic and exponential applications allow students to investigate mathematical concepts in authentic situations. This paper describes classroom examples of applications using technology in first year algebra. In addition, the use of matrix capabilities of the graphing calculator for teachers to generate their own quadratic application problems will be discussed.

As technology permeates society, it has become essential that mathematics teaching and learning take full advantage of the many applications of computers and calculators in the classroom. Traditionally, teaching in first year algebra has emphasized direct instruction of routine procedures with abstract symbols placing little emphasis on conceptual understanding and applications of mathematics (Weiss, 1987). The National Council of Teachers of Mathematics' Curriculum and Evaluation Standards recommends that students be involved with investigating, making conjectures, and constructing their own conceptual schema (NCTM, 1989). Utilizing the graphing capabilities of calculators and computers, it is now possible for students to explore visual representations of the abstract concepts. Technology allows numerical and problem solving techniques to be accessible to all students. As a result, first year algebra can be the "gateway" rather than the "filter" to the attainment of mathematical proficiency (Edwards, 1990). With technology, the new curriculum for first year algebra places more emphasis on problem solving, functions, and graphing. Applications are used to give meaning to the abstract symbols encouraging student discourse and greater student understanding (Wagner and Parker, 1993).

Problem Solving in Algebra

Problem solving strategies can be introduced at the beginning of the algebra course then continued to be applied throughout instruction. While developing the concept of variable, students can generate patterns then write a variable expression to represent a generalization of the pattern. Patterns can be linear, quadratic and exponential. Consider the following problem that can be analyzed on a spreadsheet.

A. Tosha is designing a rectangular pasture for her horse using 100 meters of fence. What length and width for the pasture would give the maximum area?

B. What length and width would give the maximum area if 600 meters of fence are used? What pattern do you notice about this problem? Test your hypothesis by trying another problem following your pattern.

Table 1 depicts the student generated data from the spreadsheet and a graph that was drawn. Students can use the spreadsheet to continue to collect data for part B then make up their own problem to test their hypothesis. They can conclude from their experiment that the shape of the pasture for the maximum area is the square.

thus exposing the students to the expert's problem solving processes. Some of these challenges, created by some persevering students through repeated, and clever use of overlapping colored shapes, in combination with the Erase feature (which whites out a whole area), were indeed challenging even for the teacher and researchers (e.g. see the third example in Figure 2 above). Activities such as the ones described above often involved an element of competition, while they also usually involved cooperation among students.

Conclusion

The classroom environment described above shares many of the characteristics of a cognitive apprenticeship and situated learning environment. It should be pointed out that while the Microworld software and materials were indeed essential for such an environment, it was the classroom teacher who played the central role in creating the learning environment and classroom culture that accompanied the Microworld activity. Through providing appropriate guidance and support, stimulating her students to engage in Microworld-related problem solving, reflection and discussion, encouraging group work, acting as the class 'expert' while modelling her own solution processes to student-generated challenges, creatively linking the Microworld work with other classroom topics and activities, this teacher helped create a cognitive apprenticeship environment and learning culture in her classroom. For the students within this culture, Microworld related activities were indeed authentic.

References

Brown, J. , Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher*, 18(1), 32-42.

Cohen, R., and Geva, E. (1989a). Designing Logo-like environments for young children: The interaction between theory and practice. *Journal of Educational Computing Research*, 5(3), 349-377.

Cohen, R. (1990). Computerized learner supports in pre-Logo programming environments. *J. for Research on Computing in Education*, 22(3), 310-335.

Collins, A., Brown, J. & Newman, S. (1989). Cognitive apprenticeship: Teaching the crafts of reading, writing, and mathematics. In *Knowing, Learning, and Instruction: Essays in Honour of Robert Glaser.* Edited by L. Resnick, Lawrence Erlbaum Associates: New Jersey.

Damarin, S.K. (1993). Schooling and situated knowledge. Travel or tourism? *Educational Technology*, 33(3), 27-32.

Papert, S. (1980). *Mindstorms.* New York: Basic Books.

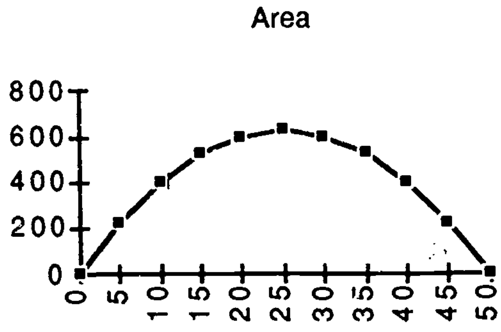
Steibel, M. J. (1989). Instructional plans and situated learning. *Journal of Visual Literacy*, 9(2).

Young, M. F. (1993). Instructional design for situated learning. *Educational Technology Research and Development*, 41(1), 43-58.

Table 1 Spreadsheet Data to Determine the Maximum Area

100 Meters

Length	Width	Area
0	50	0
5	45	225
10	40	400
15	35	525
20	30	600
25	25	625
30	20	600
35	15	525
40	10	400
45	5	225
50	0	0



New Emphasis on Functions and Graphing

Past goals in algebra were: 1) simplify, 2) solve, and 3) graph. With the new curriculum, these goals are reversed: 1) graph, 2) solve, then 3) simplify (Kysh, 1991). Functions which were traditionally introduced in the second half of the course can now be taught in conjunction with problem solving throughout the year. Solving an equation such as $2x + 4 = 20$ can be viewed as a specific case from the function, $2x + 4 = y$. For example, on the graphing calculator, students can graph a function to represent the future value of a $5000 investment at 6% simple interest for n years. The equation graphed would be $y = 300n + 5000$. The student can investigate the number of years it would take to double the investment by substituting $10,000 for y. The student can use the graph to determine the number of years or solve the equation algebraically. Thus, linear graphing can be a prerequisite skill to solving equations!

Concepts that were traditionally abstract become visual and concrete with the graphing calculator. The concept of slope for many students has been merely a memorized formula. However, students can generate a table for data, write the equations and graph these on a graphing calculator, then apply the concept of slope through the application. Consider a checking account that charges a monthly rate of $5 plus $.10 a check. Students discuss the linear relationship from the graph and the concept of slope as the rate of change. Students are involved in justifying, clarifying and communicating their ideas about the graph.

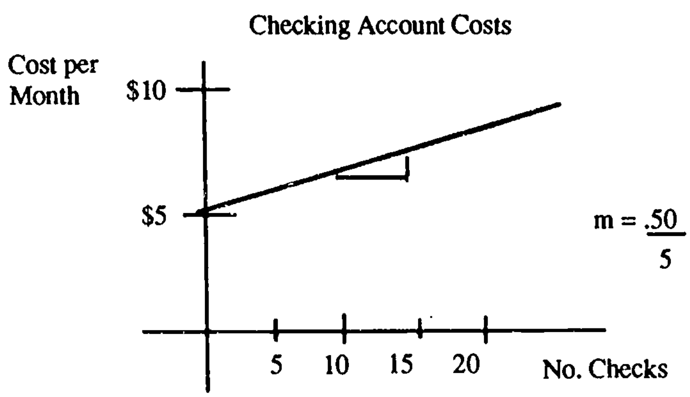


Figure 1. Checking Account Application

30

New Applications

Quadratic and exponential applications can also be introduced at the concrete level in first year algebra. Examples of maximum and minimum problems with quadratic data and applications with exponential growth can be graphed and analyzed. With the graphing calculator, students can investigate compound interest, inflation, depreciation, consumption rates, and population growth. For example, students can compare linear versus exponential salary increases.

> You are offered a job with a starting salary of $23,000. You may choose to take a salary increase agreement that is a 5% increase every year or a $2000 per year increase. Which contract should you choose if you plan to work for the company about 6 years? Which should you choose if you plan to stay with the company for at least 30 years.

Students write the equations for the two contracts:

$$y = 23000 + 2000x$$

$$y = 23000(1.05)^x$$

The equations can be graphed. Using zoom and trace, students determine that for six years, the linear increase yields the higher salary, however, the exponential percent increase is a better choice over thirty years.

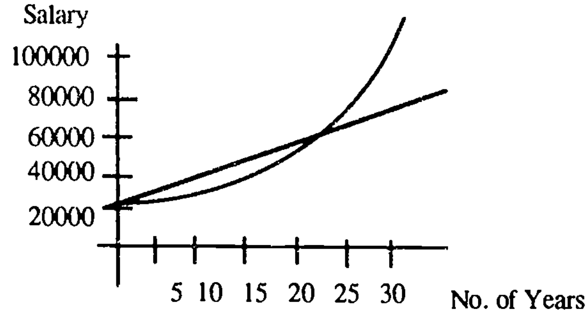


Figure 2 Salary Increases: Linear and Exponential

Technology Empowers Teachers, Too!

How can teachers who traditionally took their problems directly from the mathematics text design new quadratic application examples for their classroom? One way is to watch the newspaper and use the matrix capabilities of the graphing calculator! In February 1993, the graph in figure 3 appeared in an article about the federal deficit in USA Today. However, the equation for the graph was not in the paper! From the graph, a teacher can write the equation using the graphing calculator and matrix algebra. The following application problem can then be used in the algebra classroom by giving the equation to the students:

> Does the Government Need to Reduce the Federal Deficit?
>
> The federal budget hasn't been balanced since 1969 with the government now borrowing $1 million every minute of the day. A model developed with data from the Congressional Budget Office, Institute of Policy Innovation, can be used to predict the deficit for the next 10 years with the equation: $y = 4.8x^2 - 13.5x + 310$, where x is the number of years with 0 = 1993 and y is the deficit in billions of dollars. (Baumann, 1993; Crawford, 1993)

Graph the equation on your calculator. Use the trace key to answer these questions. What was the deficit in 1993? According to this model, in how many years will the deficit reach 500 billion? Describe the deficit over the next 5 years according to this model.

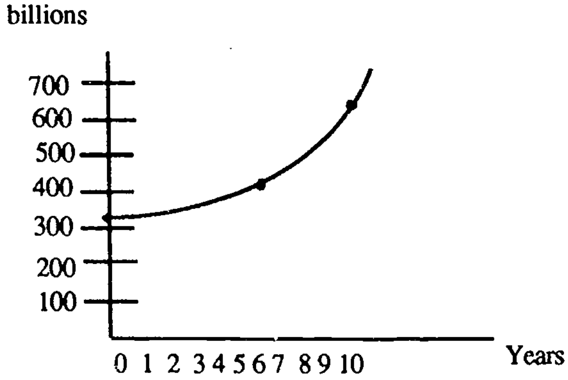


Figure 3 Federal Deficit, Prediction in Billions of Dollars
(0 = 1993)

<u>Note.</u> Graph is from "Why We Can't Put Off Reducing the Deficit" by M. Baumann, <u>USA TODAY</u> Copyright 1993, USA TODAY. Reprinted with permission.

To write the equation for the classroom application from the graph that appeared in the newspaper, first, read any three ordered pairs from the graph. One must assume that the graph can be modeled by a quadratic equation with a restricted range in the first quadrant. Substitute the x and y values for the ordered pairs into the general quadratic equation $y = ax^2 + bx + c$, to obtain a set of equations:

Ordered Paris: (0, 310), (6, 400), and (10, 650)

Equations:

$$a \cdot 0^2 + b \cdot 0 + c = 310$$
$$a \cdot 6^2 + b \cdot 6 + c = 400$$
$$a \cdot 10^2 + b \cdot 10 + c = 650$$

To solve for a, b, and c, set up the matrices A , X and B. Matrix A contains the coefficients in the equations, matrix X contains the variables a, b, and c, and matrix Y contains the constant terms.

$$A = \begin{bmatrix} 0 & 0 & 1 \\ 36 & 6 & 1 \\ 100 & 10 & 1 \end{bmatrix} \qquad X = \begin{bmatrix} a \\ b \\ c \end{bmatrix} \qquad B = \begin{bmatrix} 310 \\ 400 \\ 650 \end{bmatrix}$$

Now, enter matrices A and B into the graphing calculator. By solving the matrix equation $AX = B$ apply the inverse matrix operation, $X = A^{-1}B$, and the coefficient a, b, and c are obtained.

$$X = \begin{bmatrix} 4.75 \\ -13.5 \\ 310 \end{bmatrix}$$

Substituting the coefficients, the equation for the application is $Y = 4.8x^2 - 13.5x + 310$. Although matrix algebra is not a topic taught in algebra one, algebra one teachers have been excited to apply this process to develop good quadratic applications for their students.

Closing Remarks

It is an exciting time in the teaching and learning of algebra. Graphing calculators are now available to students. Teachers are being retrained in problem solving methodology and use of technology. New methods and technology allow algebraic thinking to be accessible to students with diverse learning styles (Stiff, Johnson, & Johnson, 1993). As researchers, we now must seriously gather the necessary data to determine the effects of the new teaching methodologies on classroom learning. Are teachers using technology to teach in the same direct instructional methods or are they asking more critical thinking questions with investigation? Are the course changes producing higher achievement in algebra? We must continue with efforts to see that teachers not only have the equipment but the training and support necessary to continue the evolution of first year algebra.

References:

Baumann, M. (1993, February 16). Why We Can't Put Off Reducing the Deficit. *USA TODAY*. p.11A.

Crawford, A. (1992). *NC MATH Algebra Project Curriculum Manual*. Unpublished manuscript. Center for Mathematics and Science Education, Chapel Hill, NC.

Crawford, A. (1993) *Applications of Nonlinear Functions For Algebra I.*. Unpublished manuscript. Center for Mathematics and Science Education, Chapel Hill, NC.

Edwards, E. L. (Ed.). (1980). *Algebra For Everyone* Reston, VA: National Council of Teachers of Mathematics.

Kysh, J. (1991). First Year Algebra. *Mathematics Teacher*, 84, 715-721.

National Council of Teachers of Mathematics (1989). *Curriculum and Evaluation Standards For School Mathematics.* Reston, VA: NCTM.

Stiff, L., Johnson, J. and Johnson, M. (1993). Cognitive Issues in Mathematics Education. In P.S. Wilson (Ed.), *Research Ideas For The Classroom, High School Mathematics.* New York: Macmillan Company.

Wagner, S. & Parker, S. (1993). Advancing Algebra. In P. S. Wilson (Ed.), *Research Ideas For The Classroom, High School Mathematics.* New York: Macmillan Publishing Company.

Weiss, I. R. *Report of the 1985-1986 National Survey of Science, Mathematics, and Social Studies Education.* Research Triangle Institute. Center for Education Studies.

The author directed the NC MATH Algebra Project that provided inservice for approximately 750 algebra teachers across North Carolina during the summers 1992, 1993 focusing on problem solving, technology, and new applications. North Carolina now requires all students to complete algebra one for high school graduation. New end of course state testing includes the use of a graphing calculator. The author edited and co-authored a set of curriculum materials distributed to the teachers for classroom use.

Towards developing a model for the implementation of CAL in black schools in the Natal/Kwazulu region of South Africa

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Abstract: This paper describes the issues arising in the implementation of computers in the context of Black schools in the Kwazulu/Natal region of South Africa. The author, as an implementor on the periphery of the schools, describes the anthropological approach taken to the said implementation. The experience points to the need to consider the double innovation approach when designing, developing or supplying computers and software for education.

Background:

The legacy of apartheid manifests itself no more brutally than in the sphere of education. As at 27th April 1994 when the first democratic elections were held for the adult population of South Africa, there was in place 14 extremely beaurocratised education departments. These departments could roughly be divided between privileged and highly resourced White departments and underprivileged and varying degrees of under-resourced black departments. Black schools do not, with very few exceptions, have access to basic resources such as text books, proper classrooms, laboratories and adequately trained teachers and thus certainly not to computers.

Figures for 1991 (Table 1) indicate that 39% of "african" students writing the school leaving (matric) examination in 1991 passed compared to the 96% pass rate for their white counterparts. Those who obtained the basic university entrance qualification (exemption) was 10% and 41% respectively.

Table 1 : Standard 10 EXAMINATION RESULTS BY DEPARTMENT, 1991

Department	Candidates	Total Pass	%	Exemption	%
KwaZulu	47 357	16 338	34	3 894	8
"African" Total	306 480	120 528	39	30 989	10
White	65 933	63 504	96	27 356	41

Source: Edusource Data News September 1992, Education Foundation

The state departments were unable and/or unwilling to address the imbalances that existed in education. It was primarily in an attempt to redress these inequities in education that educational NGO's (Non-Governmental Organisations) were born. These organisations were funded through various sources including the private sector and foreign governments. They were independent of the state education structure and by and large involved themselves in projects aimed at addressing educational needs in disadvantaged communities. These NGO's, for various reasons, tended to focus their activities. These activities ranged from pre-school, primary science, distance education, career guidance to senior science.

The Centre for the Advancement of Science and Mathematics Education (CASME) is one such NGO. Its stated mission is to "... contribute to the advancement of science and mathematics education through the development of sustainable models for the professional development of educators." CASME's focus is on science and mathematics in the last two years of schooling (matric). During its 8 years in existence its activities directly involved both students and teachers, but has tended in recent years to focus more broadly on in-service training to teachers.

Tables 2 and 3 reflects the science and mathematics results for 1992. 15% of all "african" candidates in matric wrote the science examination compared to 43% white. Of the total candidates, 7% of "african" students and 43% of white students passed the science examination. Correspondingly, of the 24% of "african" students writing the mathematics examination, 7% of the total candidates passed. 63% and 60% of the total white students wrote and passed matric mathematics respectively. The figures for KwaZulu shows a similar trend to that of the national figures.

Table 2 : Standard 10 Examination Results in Science, 1992

Department	Total Candidates	No. Writing Science	No. passing Science
DET	92 522	18 820 (20%)	9 309 (10%)
KwaZulu	46 562	5 461 (12%)	2 573 (6%)
"African" Total	342 848	50 791 (15%)	24 965 (7%)
White	66 141	28 386 (43%)	27 838 (42%)

Source: Edusource, Education Foundation

Table 3 : Standard 10 Examination Results in Mathematics, 1992

Department	Total Candidates	No. Writing Science	No. passing Science
DET	92 522	28 597 (31%)	8 610 (9%)
KwaZulu	46 562	12 658 (27%)	3 136 (7%)
"African" Total	342 848	83 933 (24%)	23 868 (7%)
White	66 141	41 720 (63%)	39 929 (60%)

Source: Edusource, Education Foundation

CASME thus rose to the challenge of addressing the extremely poor mathematics and science results as well as to foster an interest in these subjects in the Natal/KwaZulu region. Part of this strategy was the formation of CiSP (The Computers in schools Project) in August 1992. The Project works in schools in the urban and peri-urban areas around Durban in the Natal/KwaZulu region of South Africa. The schools are managed by one of two black education departments namely Department of Education and Training (DET) and the KwaZulu Department of Education and Culture (KDEC).

One of the tasks of CiSP was and is to investigate the role of computers in the teaching and learning of mathematics and science in the context of a black school. It also set out to formulate a model for implementing CAL in KwaZulu schools. It is the issues that arose during the implementation of these tasks that form the basis of discussion in this paper.

Conceptualisation of the CiSP

At the inception of the CiSP the following contextual realities existed for the project:

- it was a one person project
- prior initiatives to introduce computers to black students in South Africa had primarily been through outreach programs. This entailed bussing students from their schools to a technology centre that was usually a private school. Since I planned to introduce computers directly into black schools, there was thus a lack of data that could inform my implementation practice.
- CiSP "inherited" four schools from a previous mini-project that had placed two computers in each of these schools. These computers were running a wordproccessor and a South African designed school administration program.

Implementation - General issues

There were two immediate tasks I set myself as the co-ordinator of CiSP. First of these was to investigate how, why and by whom the computers had been used in the four schools, and secondly to initiate implementation of a mathematics package for use by students in a selected school.

Initial investigations at the four schools indicated the following:

- There were two computers and a printer per school, one of which was a double drive without a hard disk, and the other was a XT with hard drive.
- The computers were housed in the "administration" room in the school, which in three of the cases was the only room with adequate security
- This room was congested and was, as far as we were concerned, inaccessible to teachers
- In two of the schools there were one or two teachers only using the equipment, in another only the administrator and in the fourth the equipment wasn't being used at all

Whilst trying establish reasons for the low usage of the computer equipment we found the following:

- Teachers did not have any or adequate training
- Where teachers did have the necessary training, we found that their failure to utilise the existing equipment was largely due to the dynamics or "politics" existing in a school. Computers tended to be used in order to re-inforce a position of power and/or to re-inforce existing divisions. In a couple of instances the lines of demarcation were racial. In one other instance it was between teachers who had and

hadn't supported strike action. Other more subtle divisions existed along gender and along structural lines. In all cases these divisions manifested itself as those who controlled the technology and those who didn't.

Based upon both the project's and schools' initial realities as sketched in the above points, the following strategy was embarked upon:

Training was done on two levels. The first of these was more intense off-site training in a commercial word processor and spreadsheet. Secondly, training was done by regular on-site visits. All teachers at the schools were invited to attend the off-site training on a voluntary basis. Although teachers generally expressed a need for them to keep abreast of the "computer age", less than 50% took the opportunity to receive training. Each of the courses were conducted over two afternoons.

Loss of learning time due to unscheduled disruptions is a major problem in the schools in KwaZulu/Natal. O'Neill in a discussion paper highlighted the problem of loss of time in black schools in the Durban area of Natal. He states " ...reviewing records of school visits for two schools where I have worked over a one year period revealed that ...almost one third of the teaching year is lost to disruptions to the normal school activities...". So as not to contribute further to this problem, I was always very wary not to schedule -wherever possible - activities such as training and on-site visits during teaching time.

The schools were geographically widely spread with the two furthest being 60km apart. **On-site visits** to each school could thus be done on a weekly basis at most. The time for these visits were negotiated with ourselves and those teachers who had received off-site training. These visits, although being, from our perspective, extremely labour and time intensive, afforded us the opportunity of:

- identifying training needs and/or deficiencies
- offering personalised training to teachers. (Teachers were actively encouraged to utilise the technology and to log any problems and suggestions. These could then be raised at these on-site visits)
- evaluating hardware and software requirements on an ongoing basis, and where possible, acting upon these requirements
- getting to know and understand the dynamics existing in the schools and the surrounding community

Ongoing reflection and analysis during this initial implementation process revealed the following:

Of the teachers receiving initial training, three different categories arose. Firstly those who, for whatever reason, did not utilise the technology. Secondly those who used it whenever the need arose (preparing examinations papers, etc.). Thirdly those who went beyond what was taught, both in the investigating of the capabilities of the specific package taught as well as to start to question the possibility of the broader applications of the technology in their classrooms. (It was from this very tiny third group of teachers that we identified candidates to participate in a project at the start of 1994 to investigate the role of a single computer in a mathematics, science or biology classroom).

Existing power relations around the technology continued to prevail in some cases. Where we felt this was an impediment to teachers' free usage of the equipment, we embarked upon a strategy to change this in as diplomatic a manner as possible. This typically involved suggesting the principal take action. In a particularly extreme case we had to threaten withdrawing the equipment from the school. This gave us and the marginalised teachers the required results, but unfortunately not without completely alienating the two guilty teachers.

Besides the 4 schools, we were constantly getting requests for training, support and backup from teachers from other schools. Some of these schools had computer/s that had been funded or donated by a private company or a university. In about 90% of the cases these computers were not being ustilised. The technology had been placed in the schools without teachers receiving training and support in its usage, pointing to the importance of double innovation considerations - the innovation has to have the implementation strategy built into it.

Implementing CAL package for use by students

The extremely low pass rate of mathematics students in KwaZulu is reflected in Table 3. This has serious implications for students trying to gain entry into university, technikons and the job market in a society that places a very high value on having attained a pass mark in mathematics.

It was in this context that it was decided to pilot a South African designed mathematics CAL drill and practice package, SERGO in a KwaZulu school. The package covers the South African secondary school syllabus from standards 6 to 10 (last 5 years of schooling). The package has a management feature that allows the teacher to monitor pupil's performances as well as manage their route through the exercises. It had been designed for and used primarily in white South African schools for remediation.

We were allowed, by the KDEC, to choose one of three schools as the pilot site. The schools were rated on things like:

- the availability of a room to house the computers as well as electricity and the necessary furniture
- the availability of adequate security
- mathematics teachers who were enthusiastic about using the computer as a tool in the teaching of mathematics
- a principal (head teacher) who would be committed to the implementation of the project
- students doing mathematics from standards 6 to 10.

Two of the three schools qualified based on the above criteria. Whilst both were situated in areas that were characterised by violence our choice was the school that would be most accessible, with respect to both distance and safety, by ourselves. The school, Kwa-Makhutha Comprehensive High School, is situated approximately 25km south of Durban in a township of the same name. The school had prior to 1992 only offered standard 9 and 10. Due to amongst other things a donation from an automotive company which drew its workforce from the area, the school was upgraded to comprehensive status by offering both an academic and technical streams. This upgrade in 1992 also co-incided with the school offering standard 6, standard 7 in 1993, etc. until it become a fully fledged high school in 1994. Thus, at the start of implementation the school was registering students for both standards 6 and 9 from surrounding feeder schools. This meant at these levels teachers were faced with having to teach students from varying academic backgrounds. This posed a problem for the mathematics teachers in that, in the extreme cases, some students came from schools where there were no mathematics teachers and/or no other resources, and various other circumstances that served to disadvantaged the student. Although it was not a stated intention of both ourselves or the teachers, we found that the software helped greatly to begin to address this problem of equity in the mathematics class.

A network of 12 computers and a printer was installed in what was to be a "dedicated" room in the school - 11 workstations and a file server. Novell 3.1 was chosen as the operating system., and for the period of the pilot (a year) the only software installed was SERGO. The school had two mathematics teachers, both very confident with their subject. Both had very little prior computer experience. A few weeks after installation one of the teachers stated the following as the purpose of the project:

"... to help teachers present mathematics in a lively, exciting and intelligible way"

"to inculcate in pupils a love for, an interest in, and a positive attitude towards mathematics"

"to stimulate the pupils eagerness to learn mathematics independently"

"to give the pupils the opportunity to gradually master mathematics with the use of computers as the vehicle"

"... to close the gap between theory and practice."

He furthermore reported his initial findings, some of which together with the above purposes re-inforces Schoenmaker et al's assertion that "... the use of computers ... sometimes seems to be of value in itself ... one should also think of the goals of using a new technology and about possibilities arising as a result of the new technology. " These findings were:

"the pupils were all excited by the prospect of studying mathematics through computers."

"the look of ecstasy on the pupils faces proved that all of them just loved to work at the computers. they derived pleasure by just making them work."

"rewards for partial success and victory were powerful incentives for them to work more accurately"

Even at this early stage in the project he was experiencing that new technology and/or software implied extra time, commitment and management skills on the part of the teacher when he further reported in his findings:

"the teacher must however keep constant surveillance because the most active and aggressive (in the group of pupils) simply take over the machines and do not want to share"

"a preview of the topics by the teacher is important"

"time seemed to go too fast and the periods overlapped"

A salient feature of black schools in South Africa is the large class sizes. The teacher stated in his initial report that he foresaw this, in conjunction with limited contact time, being a problem. A specific example he gave was that there were 74 students in his standard 9 mathematics class, and as the package was a "drill and practice" , implying optimum usage would be gained if students could use it on a one on one basis. As the package demanded he be available at call to students at the computers, if each student had 30 minutes computer contact time per week, he would have no teaching time left for that class. He none the less made the following initial recommendations:

"to accommodate large classes, more sitting furniture should be added in the computer room"

"each student should be allowed a double period (± 60 minutes) per week"

"ratio of students per computer be 1:1 at any specific point in time"

"two teachers should ideally be available per computer session" - he did note that this would not be possible at that time

"more time will be needed by mathematics teachers for effective previewing of programmes to be run and for preparing their students for these programmes"

As was predicted, the teachers encountered an enormous amount of difficulty trying to manage the resource. This was born out by their statements at evaluation:

"the major difficulty was that of planning, time-scheduling and initiation. However teaching becomes more of challenge and responsibility."

"computers make great demands on me. In the morning sessions I have to supervise the pupils thus relegating some of the (other) activities"

"obviously the teacher roles of being a classroom manager and record keeper are extended.

a) he becomes a tutor that instructs by alternative methods including lecturing, demonstrations, etc.

b) he previews and evaluates the programs proposed for adoption

c) he sees to the servicing and maintenance of the microcomputers

d) he supervises the general cleanliness of the computer room"

One teacher, however, made himself available to supervise the computer room during non-formal teaching time. He allowed students to utilise the equipment for an hour before school started, during lunch break and for about an hour after school. Students were and are always queuing in order to utilise the equipment during this voluntary time. Other positive observations at evaluation relating to the introduction of the technology into the school included:

"pupils differ in ability and rate of learning. Computers allow drill and practice for slow learners, time pressure is reduced. Through this they are reassured by the sense of accomplishment, feel pleasure in achievement and thus find high motivation to do more work. Able pupils are given the opportunity to do accelerated work."

"using the computer as an aid in tutoring mathematics is especially appropriate. The computer permits instruction to proceed whilst teacher attention is directed towards helping other individuals or groups. "

"the computer has helped me as a teacher in building pupils' self-concept and self-image and it does help to intrinsically motivate pupils to learn and see themselves as part of the technologically advancing world"

" ... excitement is totally shown by pupils when entering the computer room."

"...there has been drastic improvement in the pupils ability to do mathematics. First quarterly tests in 1993 and computer progress reports confirm this."

Negative comments coming from the mathematics teachers are:

"I have nothing against the use of computers for teaching mathematics, but I would suggest that pupils' motor neuron abilities must be looked after, for example in sketching of graphs...."

"... pupils are deprived of chances to show innovativeness. Instead I see the learning mathematics on computers as a form of recipe as its exercises are followed slavishly on the screen."

Comments from teachers and students who the technology wasn't targeted at were largely negative. One non-mathematics student interviewed commented:

"I see the need to know the computer... I do not like the idea that the computers are only used for the mathematics students - it makes me sick!. The impression created is that computers are only for mathematics/scientific people... I feel that those who do use the computers are very lucky and should make the most of the opportunity. "

Reaction from the mathematics students were largely positive. Problems that arose from these students were those relating to insufficient access time and being forced to work in a group.

Conclusions

By far the most overriding feature of the implementation process was the positive attitude from both teachers and students. For teachers it appears to be empowering to be able to in the first instance demystify computer technology and, in the long term, reduce the workload involved in as well as improve the quality of classroom materials development. When time allows it offers them a chance to expose their students to broader applications of the subject content. As it was put by one teacher when asked by myself whether a particular package might be problematic because it does not conform rigidly to the syllabus she replied "... it does not matter, as I am not teaching them only about science but also about life...". A current reality and talking point in South African educational circles is that of the lack of a "learning culture" in communities that were oppressed under the apartheid regime. This learning culture amongst students was eroded by a racist education policy and the resulting apathy towards learning and action this illicited from the oppressed people. As was evident from the implementation of the CAL package described earlier in this paper, students interest

in the learning of the subject increased just by virtue of introducing the technology into the subject (Schoenmaker 1989).

The introduction of computers into the context described in this paper should be sustainable. This would involve working with a manageable number of schools intensively for a finite period of time. At the end of this period a new set of schools should be taken on board whilst the first set has "hotline" contact with the implementing agency. The choice of a set of schools should be based on factors such as their geographical locations with respect to each other and approval from the relevant authorities (principals, teachers, inspectors, etc). In order for the model to be sustainable, support should involve general training, regular on-site visits and support, materials developed reflecting typical support required, intensive training for one or two teachers who will act as trouble shooters and the encouragement to form a SIG (subject interest group) with the surrounding schools.

This model is, by its very nature, one that developes quite slowly. If we in South Africa are looking to build capacity with respect to teachers who will be able to cope with the possible introduction, in the near future, of computers into schools for CAL and as a school subject, other initiatives have now to be intensified. These could include addressing the issue at both pre-service and in-service training of teachers. Furthermore, policy needs to be developed relating to the role of computers in education as even in white education departments this does not seem to be the case. Bean comments, from his investigations in these schools, that ".. there is at present in South African educational policy a considerable lack of consistency and co-ordination regarding computers in education..."

References

Bean , P. (1991) . Educational Computing in Secondary Schools of the Cape Education Department : A Research survey to assess computing facility acquisition and its utilization. *Masters in Education thesis, Rhodes University.*

O' Neill , T (1993) . Restoring Learning time - One point of leverage in the Education Crisis . *Unpublished paper.*

Schoenmaker , J. et al. (1989) . Applications of computers in technical and vocational education. *A study on request of UNESCO technical and vocational educational section.*

Using Mathematica to Visualize New Concepts in Linear Algebra

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Abstract: Mathematica is a revolutionary computer algebra system (CAS) that can be used as a numerical or symbolic calculator, a tool for graphing or as a visualization system to analyze data. One of the major strengths of Mathematica is its built in high level programming language. This provides an ideal tool for forming and testing conjectures in mathematics. In this paper, we will use Mathematica to introduce the brand new concept of fixed points of a family of matrices in linear algebra. We will also show how to use the animation and sound capabilities of Mathematica to make linear algebra come alive! In the process we will discover several conjectures and theorems.

Introduction

Consider the family of matrices

$A_t = \begin{bmatrix} a & b \\ c & t \end{bmatrix}$ where a, b and c are given real constants and t is a real parameter. We want to investigate the behavior of the family of characteristic polynomials $f_t(x) = Det(A_t - xI)$ for a changing parameter t, where I is the 2x2 identity matrix (Anton, 1991). For given values a, b and c, the following simple Mathematica program plots the graphs of the family of characteristic polynomials f_t for various t values on the same set of axes. What we have used was the Mathematica standard version 2.0 on a Macintosh IIfx platform running at a clock speed of 40 MHz. Some good references on Mathematica are Wagon (1991) and Wolfram (1991).

Program 1.1.

```
a = ? ; b = ? ; c = ? ;
A = { { a, b }, { c, t } } ;
B = IdentityMatrix[ 2 ] ;
Plot [ Evaluate [ Table [ Det [ A - x*B ], { t, -3, 3 } ] ], { x, -7, 7 } ]
```

Example 1.2. Assign a = 1, b = 2, c = 3 and press "Enter". The students will be pleasantly surprised to observe that all the graphs pass through a common point. In this particular instance, the common point seems to be approximately $(1, -6)$. The output is given in figure 1.3.

It is now time to raise some questions. Was the above a mere coincidence? To answer this question, the students can again experiment with Mathematica by using different sets of values for a, b and c. However, each time it appears as if the families of the characteristic polynomials f_t pass through some common point or a fixed point. In this way, they can form a conjecture and prove it to obtain theorem 2.1, given in the next section. This will also lead to the notion of the fixed point of a family of matrices.

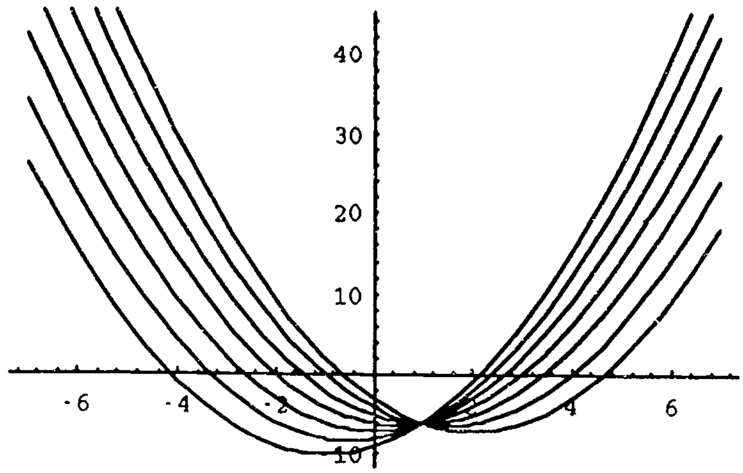

Figure 1.3

Some Interesting Theorems and the Fixed Points of Matrices

Theorem 2.1. Let $A_t = (a_{ij})$ be a family of 2x2 real matrices with $a_{11} = a$, $a_{12} = b$, $a_{21} = c$ are given constants and $a_{22} = t$, a parameter. Then the family of characteristic polynomials $f_t(x) = Det(A_t - xI)$ where I is the 2x2 identity matrix, passes through the unique common point $F = (a, -bc)$ for varying t.

Proof. It is easy to see that $f_t(x) = Det(A_t - xI) = (a-x)(t-x) - bc = t(a-x) - x(a-x) - bc$. Note that the coefficient of t is $(a-x)$. This implies that $f_t(a)$ is independent of the parameter t, and in fact $f_t(a) = -bc$. Hence for any t, all the characteristic polynomials f_t pass through the common point $(a, -bc)$. It is clear that there cannot be any other common point. For suppose (p, q) is a common point. This implies that $f_t(p) = t(a-p) - p(a-p) - bc$ must be a constant not depending on t. Hence $p = a$ and $f_t(p) = -bc$. This proves the uniqueness of the common point.

Definition 2.2. The point F in the previous theorem is called the fixed point of the family of matrices A_t or more appropriately, the fixed point of the family of characteristic polynomials f_t.

A curious student might want to know a whole lot more. Clearly in our 2x2 case all the characteristic polynomials are parabolas. Figure 1.3 might suggest that the fixed point F is also the minimum point of one of the parabolas. Another question of interest is how F is related to the minimum points of f_t for an increasing parameter t. This is an excellent place to make use of the multimedia capabilities of Mathematica. The following Mathematica program animates the characteristic polynomials f_t for varying t.

Program 2.3.

```
a = ? ; b = ? , c = ? ;
A = { { a, b }, { c, t } } ;
B = IdentityMatrix [ 2 ] ;
u = ( a + y ) / 2 ; v = - ( ( a - y )^2 + 4*b*c ) / 4 ;
( t = - 4 ; Label [ 1 ] ; t = t + 1 ; If [ t = = 4, Goto [ 3 ] , Goto [ 2 ] ] ; Label [ 2 ] ;
Plot [ Det [ A - x*B ], { x, -7, 7 }, PlotRange -> { -15, 25 } ,
Epilog -> { { PointSize [ 1/40 ], RGBColor [ 0 , 0, 1 ], Point [ { a, -b*c } ] } ,
{ PointSize [ 1/70 ], RGBColor [ 1, 0, 0 ], Table [Point [ { u, v } ], { y, -3, t } ] } } ] ;
Goto [ 1 ] ; Label[ 3 ] ; Break [ ] )
```

Example 2.4. Assign the values a = 1, b = 2, c = 3 and press "Enter". Group the resulting sequence of graphs into a single cell and double click on this single cell to start the animation. One can even add some music into our animation. The program will plot the minimum points of the parabolas f_t in red and the fixed point F in blue. In the actual presentation, one can observe the characteristic polynomials f_t dancing to music, while their minimum points traversing a red parabola. Our students will definitely be inspired by linear algebra taught in this fashion! A few frames of the animation are given in figure 2.5.

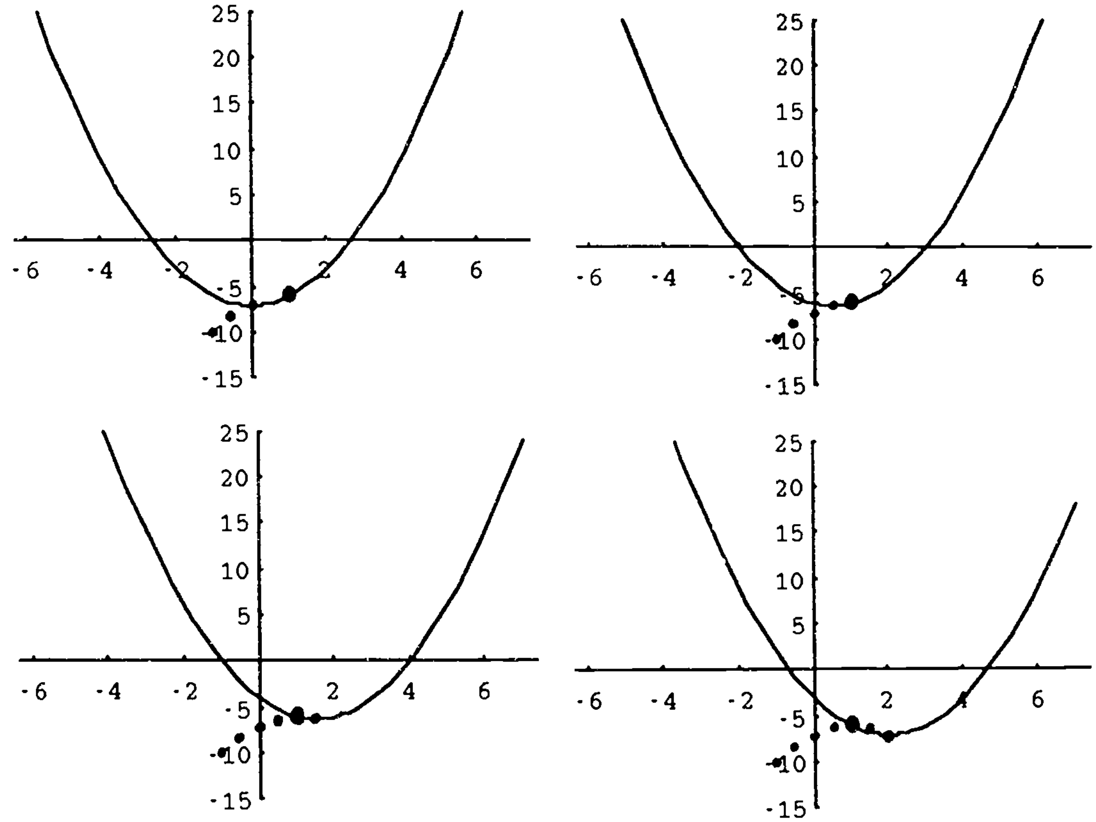

Figure 2.5

In the above example, amazingly one can notice that the blue fixed point F is nothing but the maximum point of the red parabola. One can try this for different sets of values of a, b and c. These observations will enable us to form and prove several conjectures as given below.

Theorem 2.6. Let A_t be the family of matrices given in theorem 2.1. Then for varying t, the locus of the minimum points of the characteristic polynomials f_t is a parabola. Moreover, the maximum point of this parabola is the same as the fixed point F.

Proof. It is clear that $f_t(x) = x^2 - x(a+t) + (at - bc)$. This is the equation of a parabola. Let $V_t = (\alpha, \beta)$ be its vertex. It is not hard to verify that $\alpha = (a+t)/2$ and $\beta = -\{(a-t)^2 + 4bc\}/4$. Eliminating t between these two equations yields $\beta = -(a-\alpha)^2 - bc$. Therefore the locus of V_t is the parabola $y = -(a-x)^2 - bc$ which proves the first part of our theorem. Clearly, the vertex of this parabola is $(a, -bc)$ which is the fixed point F given in theorem 2.1. ☐

The proof of the above theorem implies that V_t coincides with the fixed point F if and only if $t = a$. The next theorem answers an interesting ramification of this in terms of the eigenvalues of A_t (Anton, 1991).

Theorem 2.7. The notation is as given in theorems 2.1 and 2.6. The absolute value of the difference of the eigenvalues of A_t is minimized when V_t coincides with the fixed point F.

Proof. The eigenvalues λ_1 and λ_2 of the matrix A_t are the solutions of the equation $x^2 - x(a+t) + (at - bc) = 0$. This implies that $\lambda_1 + \lambda_2 = a + t$ and $\lambda_1\lambda_2 = at - bc$. Therefore, $|\lambda_1 - \lambda_2| = \sqrt{(\lambda_1+\lambda_2)^2 - 4\lambda_1\lambda_2} = \sqrt{(a+t)^2 - 4(at-bc)} = \sqrt{(a-t)^2 + 4bc}$. This is clearly minimized when $t = a$. However, this happens if and only if V_t coincides with the fixed point F by the comment preceding theorem 2.7. □

Now let us look back and reflect on the approach we had used so far. A CAS such as Mathematica will enable the student to experiment with mathematical or physical phenomena (de Alwis, 1993). By fully exploiting the multimedia capabilities of Mathematica, one can indeed make the experiments very lively. However, the student must keep a very open and a curious mind as these experiments are being performed. This allows one to form and test various conjectures. However, one's adventure should not stop with this. One must try to prove those conjectures mathematically. This gives the student a valuable opportunity to reinforce some important mathematical ideas. For example, in proving the previous theorems, we used certain facts about eigenvalues and characteristic polynomials of matrices. Experimenting with data before proving conjectures is an integral part of modern computational mathematics and must be stressed at an earlier stage of student's career.

Generalizations to Higher Order Matrices

A natural question is to ask whether one can generalize some of the previous definitions and theorems to families of matrices other than 2x2. To this end, consider the nxn family of matrices $A_t = (a_{ij})$ where a_{ij} are given real constants for $(i,j) \neq (n,n)$ and $a_{nn} = t$, a real parameter. One can obviously extend definition 2.2 to define a fixed point of this family of matrices as a point F such that all the characteristic polynomials $f_t(x) = Det(A_t - xI)$ pass through F. Here I denotes the nxn identity matrix. As the following theorem implies, for $n > 2$, such a fixed point may or may not exist.

Theorem 3.1. Let A_t be the family of real nxn matrices defined in this section. Then the $x-$coordinates of the fixed points of A_t are exactly the eigenvalues of the $(n-1)$x$(n-1)$ submatrix B obtained from A_t by deleting the row and column containing the entry a_{nn}.

Proof. Let $f_t(x) = Det(A_t - xI)$ where I is the nxn identity matrix. By expanding the matrix $A_t - xI$ by the last row, one obtains that $f_t(x) = g(x) + (t-x)Det(B - xJ)$ where the matrix B is as defined in the statement of the theorem, J is the $(n-1)$x$(n-1)$ identity matrix, and g is a polynomial in the x variable which is independent of t. This implies that $f_t(x)$ is independent of t if and only if $Det(B - xJ) = 0$. However, by definition, $Det(B - xJ) = 0$ if and only if x is an eigenvalue of B (Anton, 1991). Hence the theorem. □

The above theorem implies, for example, when $n = 3$, the family of 3x3 matrices A_t can have exactly one fixed point, two fixed points or no fixed points. This is because, the 2x2 real submatrix B can have exactly one real eigenvalue, two distinct real eigenvalues or no real eigenvalues. The following example illustrates the latter case.

Example 3.2. Let $A_t = (a_{ij})$ be the family of 3x3 real matrices with $a_{11} = 1$, $a_{12} = 1$, $a_{13} = 5$, $a_{21} = -2$, $a_{22} = -1$, $a_{23} = -1$, $a_{31} = -2$, $a_{32} = 3$ and $a_{33} = t$, a real parameter. Then the submatrix B described in theorem 3.1 becomes $\begin{bmatrix} 1 & 1 \\ -2 & -1 \end{bmatrix}$. A simple calculation reveals that the eigenvalues of B are $\pm i$ where $i = \sqrt{-1}$. Hence the family of matrices A_t does not have any fixed

point, because these eigenvalues are not real. One can also write a Mathematica program to illustrate that, the graphs of the characteristic polynomials $f_t(x) = Det(A_t - xI)$ do not pass through a common point in this example.

However, as the following corollary indicates, under certain conditions, the family of real matrices A_t will always have at least one fixed point.

Corollary 3.3. Let $A_t = (a_{ij})$ be a family of nXn real symmetric matrices with a_{ij} are given constants for $(i,j) \neq (n,n)$ and $a_{nn} = t$, a parameter. Then the family of matrices A_t will always have at least one fixed point.

Proof. This directly follows from theorem 3.1, since the eigenvalues of a real symmetric matrix are all real (Anton, 1991). □

References

Anton, H. (1991). *Elementary Linear Algebra.* New York, NY: John Wiley and Sons.

de Alwis, T. (1993). Effective Use of Mathematica - Pattern Recognition, Conjecture Making and Simulations, *Proceedings of the Technology in Mathematics Teaching Conference 1993, University of Birmingham, England.*

Wagon, S. (1991). *Mathematica in Action.* New York, NY: W. H. Freeman.

Wolfram, S. (1991). *Mathematica: A System for Doing Mathematics by Computer.* Redwood City, CA: Addison-Wesley.

Using Mathematics CAL in a Bridging Program for tertiary Students from Disadvantaged Communities

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Abstract
Due to the serious problems encountered in school education in the black disadvanatged communities of South Africa in the past, very few students qualify for acceptance into tertiary technology-based institutions. A special academic support program (Bridging program) is offered at the Port Elizabeth Technikon to assist students to overcome their academic disadvantages. In spite of this program problems with certain mathematical concepts prevail. A project was launched with a group of Bridging students to investigate the effectiveness of CAL to address these problems. A well known South African Mathmatics CAL Bridging System was used for this purpose. The system used is described and the project is evaluated. Systems providing computer aided learning and evaluation (testing) can be an efficient way to overcome the educational crisis of the disadvantaged communities in South Africa provided that students are motivated and enthusiastic.

Introduction

The Port Elizabeth (PE) Technikon was one of the first tertiary institutions in South Africa to observe that due to the serious problems experienced in the secondary education of blacks from the disadvantaged communities in South Africa, large numbers of these students do not pass the standard selection criteria for tertiary (post-secondary) education. The official statistics of the Department of Education and Training showed that in the Port Elizabeth area 229 out of 4 910 black students taking mathematics as a subject, i.e. 4.7%, passed their matriculation (twelfth grade) examination in 1991. Only 20 of these i.e. 0.4%, qualified for entry into a technology-based main stream education at a tertiary institution.

In July 1989 the PE Technikon decided to launch its Academic Support Program (ASP) [4], to prepare students with potential, who failed the standard selection criteria, for careers in the field of technology. Aptitude tests have been used to select some of these students to enter the ASP program. In this program students attend a so-called Pre-Technician or 'Bridging' academic year aimed to upgrade the students' school education in mathematics, science, and general communication and life skills.

The Bridging curriculum consists of :

1. A one semester Mathematics course at first year level, supplemented with extra lecture periods and tutorial sessions. Contact time is increased by 50% in comparison with the normal course. [2].

2. A one semester course in each of Physics and Chemistry revising the secondary school syllabi.

point, because these eigenvalues are not real. One can also write a Mathematica program to illustrate that, the graphs of the characteristic polynomials $f_t(x) = Det(A_t - xI)$ do not pass through a common point in this example.

However, as the following corollary indicates, under certain conditions, the family of real matrices A_t will always have at least one fixed point.

Corollary 3.3. Let $A_t = (a_{ij})$ be a family of nXn real symmetric matrices with a_{ij} are given constants for $(i,j) \neq (n,n)$ and $a_{nn} = t$, a parameter. Then the family of matrices A_t will always have at least one fixed point.

Proof. This directly follows from theorem 3.1, since the eigenvalues of a real symmetric matrix are all real (Anton, 1991). □

References

Anton, H. (1991). *Elementary Linear Algebra.* New York, NY: John Wiley and Sons.

de Alwis, T. (1993). Effective Use of Mathematica - Pattern Recognition, Conjecture Making and Simulations, *Proceedings of the Technology in Mathematics Teaching Conference 1993, University of Birmingham, England.*

Wagon, S. (1991). *Mathematica in Action.* New York, NY: W. H. Freeman.

Wolfram, S. (1991). *Mathematica: A System for Doing Mathematics by Computer.* Redwood City, CA: Addison-Wesley.

3. A one semester selection course, either An Introduction to Human Biology or Engineering Technology.

4. A two semester course in Communication Skills, including a subcourse in Computer Literacy.

5. A one semester course in Life Skills.

The last two courses have been motivated by the following observations. Research has shown [5], that most of the students from the disadvantaged communities, experience serious problems in understanding the subject terminology and expressing their misunderstandings. The lecturing medium being English, is usually their second or third language. They are therefore very hesitant to ask their lecturers for assistance.

Students accepted for the ASP can, at the end of the bridging year, apply for selection for standard Technikon Diploma Studies and receives recognition if they passed the Mathematics course in the Bridging year.

It was, however, observed by the lecturers involved that the majority of the ASP students continuing with their studies, although they have passed first year Mathematics, still have serious problems with mathematical concepts as applied in first year Physics and Chemistry. Some of the problem areas identified were exponents and logarithms, changing the subject of equations, solving word problems and trigonometry. Since a very large increase in student numbers from the disadvanteged communities is expected over the next decade, a serious effort is required to address these issues.

It was therefore, decided to consider a Mathematics Computer Assisted Learning (CAL) course to attempt to remedy these problems.

Aim of the Project

An investigation of the effectiveness of Computer Aided Learning (CAL) in Mathematics for students from disadvantaged communities in a Bridging Program at the Port Elizabeth (PE) Technikon, South Africa.

Project Application

After successfully completing the Mathematics course in the first semester, the group of ASP students preparing to study for a Diploma in Applied Science, were given a Computer Aided Learning (CAL) Computer Literacy course locally developed by the Department of End User Computing of the PE Technikon.

A Mathematics pre-test, concentrating on the mathematics problem areas, as mentioned above, were then administered. They also completed a questionaire conveying their own perceptions of their mathematics capabilities and problem areas. In this questionaire the students were given a list of the different sections of the first year mathematics syllabus and were asked to indicate to what extent (Good, Average, Poor), they thought they have managed the sections.

On completion of the pre-test and questionaire, the students were exposed to a well known South African developed Mathematics CAL Bridging Course.

The project lasted eight weeks during which the students attended two one and a half hour CAL sessions per week, concentrating on the identified problem areas. At the end of the period the students wrote a Mathematics post-test and also completed a questionaire on their perceptions of the course. The pre-test and the post-test were identical.

The students used a computer laboratory equiped with Intel 386-based microcomputers (with Super VGA screens) interconnected by a local area network.

The CAL Bridging Course

The network version of the SERGO Mathematics System Bridging Course developed and supplied by Interlearn, was used. The primary aim of this Course is to cover the most essential topics from the secondary school Mathematics syllabus and selected topics of a typical first year Mathematics course at tertiary level.

The supervisor or lecturer controls the system to allow a student to work through the whole course in the prescribed order or to follow one or more of the so-called topic related paths, e.g polynomials, equations, exponents and logarithms, functions and graphs, calculus, vector algebra and trigonometry.

Each path consists of a number of modules (116 for the complete course and from 17 to 27 for a topic related path). In order to exclude introductory or advanced levels of a topic, a path can be limited to a smaller sequence of modules. Each module, apart from covering the relevant theory and providing worked-out examples, provides a substantial number of problems to be solved by the student. The lecturer can determine the number of problems a student has to solve correctly before progressing to the next follow-up module.

The lecturer can set various norms e.g. the 'fail' option, where, if a student has incorrectly completed a specified number of problems, he is automatically taken to a remedial module. Once the student passes the remedial module he will return to the module failed before. If a student 'fails' a remedial module, he is moved back to a relevant lower level remedial module, etc. When a student terminates a session the system records his position in the set path and will allow him to continue from the last completed module.

Progress reports on the class or a specific student can be obtained by the lecturer. These reports contains information on the path(s), the specific modules completed, the number of problems attempted and the number of problems which have been completed correctly. The average time spent on each problem as well as a grading (%) for each module are given.

The marking is rather stereotype allocating 1 for a correct solution to a problem and 0 otherwise. No credit is given for correct intermediate results. Note, however, that the system was not intended to be a Computer Aided Testing or Evaluation System.
Help, providing underlying theoretical hints, is available but then no credit is given to a correct answer, in fact it is taken as a problem 'completed unsuccessfully'.

In this project the students used the system without any assistance from a Mathematics lecturer.

Evaluation of the Project

Statistical Results

The eighteen prospective Applied Science students who were selected to continue with the second semester of the Bridging program, participated in the project.

	Average percentages				No. of
Section	Pre-Test	Post-Test	Increase	Attendance	modules
Exp. & logs	32.1	38.4	6.3	84	13
Polynomials	30.0	36.7	6.7	90	11
Trig.	27.1	30.6	3.5	46	12
All	29.9	35.6	5.7	73	36

Table 1: Test scores and attendance of lessons

Table 1 give the scores of the students in the three sections viz exponents and logarithms; polynomials, and trigonometry, which corresponded to the topic related paths of the CAL system used. Under the column 'Attendance', the average percentage of the modules mastered for each path is given. Note that this figure excludes the extra remedial modules completed sucessfully. The last row contains the corresponding figures for the complete test and course.

The average mark for the group in their Mathematics examination was 59.4%. The low averages for both the tests (29.9% and 35.6%) confirm that the topics selected were indeed problem areas. However, it is interesting to note that the majority of the students (78%) rated their own understanding of the work as above average.

The improvement in performance (19% relative or 5.7% absolute), displayed by the figures in the column headed by 'Increase', can largely be attributed to the attendance of the CAL course. Although

there seems to be a correlation between improvement and attendance, there is not sufficient statistical evidence to support this.

Student Evaluation of the Course

In the evaluation questionaire students had to respond 'Yes', 'Sometimes' or 'No' to questions covering the following topics.

1. The Computer (hardware) - On eight of the nine questions e.g. 'Was it easy to learn how to use the computer ?'; 'Did you learn to use the keyboard quickly ?'; 'Were the letters on the screen big enough ?' ...etc. the responses were overwhelmingly positive. The only indeterminate response was on the question, 'Were the graphs easy to understand ?'. We believe that this may relate to perception problems experienced by students from disadvantaged communities. Compare [3] and [5].

2. The Software - On the four questions : 'Did you understand the words used in the lessons ?'; 'Did you understand the mathematical terms used ?'; 'Did the diagrams shown on the screen helped you in understanding the mathematical concepts ?' and 'Did the supervisor explain clearly how to use the program ?', the responses were strongly positive.
   However the questions 'Were the instructions on what to do, easy to understand ?'; 'Did you often have to look at the instructions to use the program ?' and 'Was it easy to type special maths characters like $\geq$, $\leq$, etc. ?', yielded indeterminate responses.

3. The lessons - The seventeen questions on whether they liked doing mathematics on the computer, thought it stimulating and whether it improved their understanding of the different topics, also yielded overwhelmingly positive responses.

4. Language The students were all happy that the lessons were in English. Amazingly, only two would have liked it to be in Xhosa which is the home language of fifteen of them.

Each section had an open ended question of the form : 'Anything else you would like to say about ...?'.

More than 30% expressed their wish to have remedial CAL lessons in other subjects as well, naming both Chemistry and Physics.

They also requested that a Mathematics and Science CAL outreach program should be established for students from the disadvantaged communities to improve their preparation for tertiary education.

Weaker students complained that they could not manage to progress in the cases where they did not understand or manage the material. The system kept on reverting them back to remedial modules without providing sufficient explanation to overcome their problem(s).

Evaluation of Project Leader

Although the majority of the students had no previous contact with computers, they adapted easily and showed a keen interest in using the computer as a tool to gain knowledge. It was also significant to see their motivation and growing enthusiasm for the project.

The reports produced by the CAL system on the progress of a group, or an individual student, are invaluable to the lecturer monitoring the progress. It identifies the students needing extra attention and the lecturer can pin-point the problems of individual students and provide problem-orientated help.

In our opinion this system can not be used without a lecturer to resolve such cases and provide the necessary remedial tutoring, since the problems of these students are more fundamental and at the basic secondary school level. Of course, the SERGO CAL High School Mathematics System could be used to alleviate this problem.

The students confirmed two important advantages of CAL : they enjoyed working at their own speed and time, and the majority spent a lot of extra time, even many a lunch break, in the computer laboratory.

Two instances were observed where the system marked a correct answer as incorrect. Although this is statistically a small error rate, the impact on the students has been severe. Once they discovered one

of these errors, the credibilty of the system was in doubt and they queried the marking. The complaints raised on this issue in their evaluation was out of proportion, but it emphasizes the importance that such errors be elimated before the release of such systems.

Due to the fact that the System regarded a problem to be unsuccessfully completed when a student used the 'Help' feature, students were unwilling to use it. This defeated its objective of supplementing the course material.

Conclusion

Tertiary Education Institutions seriously concerned with the teaching of students from disadvantaged communities can certainly benefit from CAL and Computer Aided Testing (CAT) systems. Furthermore large numbers of students can be taught effectively and efficiently provided that strict monitoring is applied to ensure that students with problems are identified timeously for personalized remedial action.

In the next couple of years it is going to be crucial to rectify the past inefficient school education of people from the disadvantaged communities in South Africa. A computer aided approach can play an important role to solve this education crisis in South Africa ([1] and [6]), provided that the students are motivated and enthusiastic.

Any computer laboratory which is not fully utilized can be used to assist large numbers of students from these communities to come level with the normal main stream of tertiary students. At most tertiary education institutions, such free capacity exists indeed, at least over week-ends and during academic holidays.

References

1 Alessi,S.M. & Trollip,S.R.(1991). Computer-Based Instruction - Methods and development. *2nd Ed. Prentice Hall, 387–408.*

2 Emery,J., & Schuman,J. & Sharwood,D.W.(1992). A Holistic Approach to Bridging Mathematics for Science and Engineering. *Proceedings of the Second Australian Bridging Mathematics Network Conference. July 1992.*

3 Rolfe,J.M.(1980). Correlation between spacial perception aptitude tests and the Brohn-Cowan tests of understanding structural behaviour. *Paper presented at a Workshop on Spacial Perception, University of the Witwatersrand, Johannesburg, SA.*

4 Sharwood,D.W.(1990). The Introduction of an Academic Support Programme for Science and Engineering Students at the Port Elizabeth Technikon. *Proceedings of the First HRSC Seminar on Academic Support Programmes and Bridging Courses in Tertiary Education for Mathematics, Science and Engineering. Pretoria, SA, July 1990, 177–183.*

5 Sharwood,D.W.(1992). Turning a Disadvantage into an Advantage. *Proceedings of the Second HRSC Seminar on Academic Support Programmes and Bridging Courses in Tertiary Education for Mathematics, Science and Engineering. Pretoria, SA, November 1992, 212–222*

6 Trollip,S.R.(1993). Computer Managed Instruction Solving the Education Crisis. *Lippert,Renate C. (Editor), Computer-Based Education and Training in South Africa, J.L. van Schaik, Pretoria, SA, 113–124.*

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Academic Support in Mathematics in a Third World Environment

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Abstract: As part of the academic support programme, a computerised bridging course in Mathematics was developed at the University of Pretoria. The didactical approach of the system is that of criterion referenced instruction or mastery learning in which the progress of the student strictly depends on proven mastery of the concepts. Each university topic is preceded by modules on the school Mathematics that is needed to understand the particular concepts and techniques involved. A description of the course is given and the success of the course so far, is discussed.

The shortage of qualified Mathematics teachers (in the black community in particular) in South Africa, places a big responsibility on Mathematics departments at the universities. First year students experience difficulty in adapting to the change from school standards to university standards in Mathematics with respect to subject content as well as the pace of the lecturing at the university, it being much faster than what they are used to at school.

Mathematics is perhaps the biggest problem since a sound mathematical foundation is needed by a large number of other subjects and because of the conceptual nature of the subject.

To address these problems, it was decided to develop a computerised bridging course in Mathematics at the University of Pretoria. This course forms part of the academic support programme at the university.

A student works through the course in parallel to the normal lectures working on the computer for two or three hours each week. By the end of the first semester a student working on the course will have caught up with his fellow students.

Description of the course

Mathematical content

We did some research on which school topics are most needed in the university subjects with mathematical content. The entire course consists of 112 modules - about half the modules covering the above mentioned topics from the high school Mathematics and the rest of the modules covering the contents of the first semester Mathematics course at the university.

The order in which the course is planned is such that the content builds up in a logical mathematical order. Each university topic is preceded by modules on the school Mathematics that is needed to understand the particular concepts and techniques involved.

The ideal situation is that a student will work through the 112 modules in this prescribed order. This will ensure that all topics are covered. This is done parallel to the normal lectures working on the computer for two or three hours each week. By the end of the first semester a student working on the course will have caught up with his fellow students.

The course also makes provision for different paths or topics. These paths are meant to solve a particular problem in a student's mathematical background. Each path consists of a number of modules and each module contains a great number of different problems.

The programme is divided into eight different paths or topics. In path 1 (the complete course) the student works through the entire course in a linear way. The other paths each covers a certain topic.

Path 1 : Complete course
Path 2 : Polynomial Algebra
Path 3 : Equations
Path 4 : Exponents and Logarithms
Path 5 : Functions and Graphs
Path 6 : Differential Calculus
Path 7 : Vector Algebra
Path 8 : Trigonometry

Unless otherwise instructed, a student will automatically begin working on Path 1 (the complete course). At any stage, however, the student can be moved to another path or to another module.

Structure of a module

The didactical approach of the entire system is that of criterion referenced instruction or mastery learning in which the progress of the student strictly depends on proven mastery of the concepts.

According to Bigge (1982:307) "Mastery learning offers a powerful new approach to student learning which can provide almost all students with the successful and rewarding learning experiences now allowed to only a few."

In the system this is used in the following way: Each module begins with an explanation of the theory and concepts needed to solve the problems. This tutorial section is optional and some students may decide to skip this section. This section normally contains some worked examples.

After this the student has to do a number of problems on the topic. Before a student is allowed to continue with the next module he has to prove to the computer that he has mastered the concept involved by satisfying certain predetermined progress criteria.

According to Poppen & Poppen (1988:39) it is important that certain behaviouristic principles should be used when developing quality courseware. Two of the most important of these principles, built into the system, are immediate feedback and hints supplied by the computer. A help function is included into the system to enable the student to get information without actually asking the lecturer. Guidelines are given to encourage the student to think positively towards a solution of the problem.

User friendliness is a high priority. The student is addressed on first name terms while encouragement and advice are given throughout. If the answer supplied by the student is correct but not in the format expected by the computer, it will be accepted as correct with a remark on what would be a better format in which the answer should be given.

Students working on the system

The lecturer controls the entire process from a central control unit. As soon as a student satisfies the progress criteria of a particular module, he will automatically be moved to the next module by the computer.

The lecturer can decide on the progress criteria for any particular module. The criteria that can be altered are the following.

Should second correct answers get credit?
How many problems must be done correctly?
Must the problems be done correctly in a row?
Is there a fail criterium?
How many incorrect answers for the fail criterium?
Is there a time limit?
If yes, how long?

Progress reports

The system keeps complete record of each student's progress in every module. This information is accessible as a hard copy or can be read on the screen. The system makes provision for two types of reports.

Class reports contain the names of the students in a class arranged alphabetically. In every topic a reading is given for each student giving a percentage of the exercises completed in the particular path. This enables the lecturer to detect students having problems with certain topics in the subject with a single glance.

Individual progress reports contain detailed information on each module completed by the student, indicating the date, number of problems done, number correct and the average number of seconds spent on a problem. This report supplies valuable information to the student as well as to the lecturer.

Remediation

Remediation is an important and powerful component of the system. Its diagnostic features have the effect that unique problem areas of a student are immediately addressed and can be remedied. This can be done automatically by the system or the lecturer can control the remediation process using the results of the progress reports.

Automatic remediation can be accomplished by determining the progress criteria for each module. For each module in the system, there is an "escape" module. This is a module on the same topic but of an easier nature. If a student "fails" a module by satisfying the fail criteria, he is automatically moved backwards to the particular escape module.

This "fail" option makes special provision for the weaker student. It is an ongoing diagnostic process, doing automatic remediation of topics which can be considered as bad spots in the student's mathematical background. This process ensures mastery before a student is allowed to move on to new content.

By analysing the results of the progress reports made available by the system, the lecturer can immediately detect the weak areas in a student's mathematical background. Using the flexibility of the system, he can now move the students to the relevant modules in the system.

A homework booklet containing a homework exercise for each module, has been compiled. When a student's computer session is ended, a summary of the exercises completed in that session appears on the screen. The student hence knows exactly which homework exercises he has to do for the next session.

Experience in 1991 and 1992

First year Mathematics students with a D symbol in Higher Grade matric Mathematics are advised to follow the course. Unfortunately there is an enrolment fee (we had to buy computers and employ assistants) so 99 students entered the course in 1991 and 90 in 1992.

Lets begin with a success story by mentioning four exceptional cases. Our first year Mathematics course consists of two (equal in weight) sections: Calculus and Algebra.

Table 1
Some extreme cases

Student number	Matric symbol	Algebra %	Calculus %
9204326	D	75	81
9254749	D	72	78
8642818	E	62	70
9243828	E	65	64

In our first year the biggest group of students are engineering students - so we distinguished between engineering and non-engineering students.

We compared the results of bridging course (BC) students to those of the other D symbol students that did not take the course (NBC).

Non-engineering students

In 1992 there were 122 non-engineering students (with D symbol in Matric Mathematics) that wrote the semester examination of which 86 were NBC-students and 36 BC-students. All students were examined in Algebra and Calculus separately.

Table 2
Number of non-engineering students (n), average mark ($\overline{x}$) and standard deviation (s)

Algebra		Calculus	
NBC	BC	NBC	BC
$n = 86$	$n = 31$	$n = 82$	$n = 36$
$\overline{x} = 49.186$	$\overline{x} = 57.903$	$\overline{x} = 45.122$	$\overline{x} = 52.083$
$s = 14.428$	$s = 15.263$	$s = 14.529$	$s = 17.500$

Using the method of hypothesis testing to compare the averages of the two independent samples, it appears from the analysis that the performance of the BC-students was significantly better than those of the NBC-students.

Engineering students

Engineering students have a combined mark for Algebra and Calculus. Of the 105 students (with D symbol in Matric Mathematics) that wrote the examination, 72 were NBC and 33 were BC-students.

Table 3
Number of engineering students (n), average ($\overline{x}$) and standard deviation (s)

NBC	BC
$n = 72$	$n = 33$
$\overline{x} = 46.389$	$\overline{x} = 54.091$
$s = 13.141$	$s = 12.084$

Here again the average performance of the BC-students was significantly better than those of the NBC-students.

Questionnaire

A questionnaire was used to get feedback from the students that took the bridging course on how they experienced the course. Included some of the questions with responses.

Question 1: *To what extent did your self confidence in Mathematics improve?*

54

Table 4
Answers to Question 1

Choices	Very much	Somewhat	So-so	Little	Nothing	Total
Percentages - 1991	23	58	17	2	0	100
1992	25	46	27	2	0	100

In 1991 81% of the students felt that their self confidence in Mathematics improved "Somewhat" to "Very much" while in 1992 the percentage was 71%.

Question 2: *To what extent did your understanding of Mathematics improve?*

Table 5
Answers to Question 2

Choices	Very much	Somewhat	So-so	Little	Nothing	Total
Percentages - 1991	37	55	7	1	0	100
1992	40	51	7	2	0	100

From this table it is clear that in both years 91-92% of the students' understanding of Mathematics improved.

Question 3: *Your general impression of the course?*

Table 6
Answers to Question 3

Choices	Very good	Good	Average	So-so	Bad	Total
1991	45	51	3	1	0	100
1992	42	51	7	0	0	100

About 95% of the students in each year consider the course to be "good" to "very good".

Conclusion

The average performance of students in the bridging course was significantly better than the other students with a D-symbol in matric Mathematics for engineering as well as non-engineering students. Furthermore, students experienced the course positively.

Our experience is that the success of the course depends highly on the measure of human involvement by the supervisor. Leaving students on their own in the computer laboratory will definitely have an effect on the results.

A shortcoming in implementing the course is the fact that students do not get any credit for the course. It becomes difficult after a time to motivate the students to work regularly.

References

Bigge M.L. (1982). Learning theories for teachers. Fourth edition. Harpei and Row, New York.

Poppen L., & Poppen R. (1988). The use of behavioural principles in educational software. *Educational technoiogy, 28(2)*, 37-41.

Attaching Media-Rich Information to Collaborative Biology Knowledge Networks

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Abstract: A knowledge network construction tool (SemNet) has been developed and used successfully in many science classrooms. Five years of use in a biology class for prospective elementary school teachers has resulted in learning improvements, such as increases in deep processing, categorization skill, and hierarchy construction. New software functions and instructional methods to support collaborative net creation by small groups of students have been used to support integration of concepts into an elaborated mental model, and to improve understanding by exposing students' alternative views for consideration and discussion by peers and instructors. New functions have been created for attaching documents using other media such as audio, video and graphics to nodes and links in a knowledge network. This enables students and teachers to enrich their conceptual representations with information organized or represented differently, or to organize and access databanks of images and documents from multiple viewpoints.

Our research group has developed and tested a multidimensional knowledge construction tool, SemNet® (Faletti, Fisher, Lipson, Patterson & Thornton, 1991), which provides support for thinking about ideas in complex domains (Fisher, Faletti. Patterson, Thornton, Lipson, & Spring, 1990). SemNet has been used by students in several dozen classrooms at various grade levels ranging from sixth grade to post-graduate (for example, Fisher and Thornton, 1987; Brody, 1990a, 1990b; Jay, Alldredge, & Peters, 1990). Each of these studies found evidence that SemNet in its present form can be a useful knowledge construction tool for students. It has been used successfully for many different purposes and at many different levels including: as a learning tool for middle school students (e.g., Jay, Alldredge, & Peters, 1990); for secondary biology students (e.g., Huppert, 1988); and for college biology students (e.g., Gorodetsky, Fisher, & Wyman, 1994); as a tool for diagnosing biology misconceptions (Fisher, 1994); as a curriculum design tool (Allen, Kompella, Hoffman, & Sticht, 1991); as a cognitive research tool (Gordon, in press; Hoffman, 1991); and as a communication tool for a working committee of the European Common Market (Hofmann, & Welschselgartner, 1990). It has also been used to produce nets in many different languages, including Japanese, Hebrew, German, French, and Spanish.

SemNet was designed so that biology students with no computer experience required less than two hours of instruction before they could begin focusing on the content they were to learn. SemNet was designed primarily to help students focus their attention on weaving individual pieces of knowledge together to construct an integrated, cohesive, meaningful whole. In designing SemNet, the needs of instructors and researchers have also been considered, particularly as a tool for organizing their own knowledge and studying students' knowledge. The SemNet interface, which is based in part upon semantic network theory describing the organization of ideas in long term memory (Kintsch, Miller & Polson, 1984; Norman, Rumelhart, & the LNR Research Group, 1975; Quillian, 1967, 1968; Sowa, 1983), appears to be intuitive and readily comprehensible. Some of the key ways in which SemNet has been used are described below.

As a knowledge construction tool, SemNet prompts users to organize their ideas in systematic ways, link ideas together with explicitly named relations, and create rich descriptions for important points. As a tool for reflection, SemNet captures and mirrors a thinker's thoughts, serving as a long-term extension of limited capacity short term memory. Users can reflect at leisure upon the ways in which they have organized and

described their ideas, and can edit and reorganize them easily. They can also learn by looking over the shoulders of their peers, seeing how others organize the same knowledge. When used by our students, this results in a consistent significant increase in deep processing among high aptitude students, as measured by Schmeck's Inventory of Learning Processes (Schmeck, Ribich & Ramanaiah, 1977; Schmeck & Ribich, 1978). Similarly, we believe significant growth of cognitive skills (such as categorizing and constructing hierarchies) occurs among low aptitude students, although we do yet not have a quantitative measure of these gains (Fisher, 1994).

As an analytic tool, SemNet offers users many different perspectives of their knowledge, including overviews and 'subviews' (such as the main ideas and hierarchies in a network), along with precise quantitative summaries of network characteristics. As a collaborative tool, SemNet allows individuals to compare their thinking and negotiate meaning at a finer grain than is possible in written and spoken language. We have studied students constructing nets alone, in pairs, and in groups of three or more. Preliminary evidence suggests that the greatest gains result from collaborative efforts involving three or more students, consistent with (Heller, Keith & Anderson, 1992) and (Heller & Hollabaugh, 1992). In this format, each individual develops and enters ideas independently and then the group collaborates in planning, review, and revision.

Finally, as a research tool, SemNet provides many insights into cognitive function. It offers a rich and unobtrusive means for exploring alternative conceptions, the nature of relationships, and the 'structure' of personal and public knowledge. It also reveals students' habits of mind by revealing their choice of ordering, focus and grain-level when describing a topic.

In a sense, SemNet is to thinking as molecular biology is to biology: it permits us to ask questions at a level of detail heretofore unimagined. Among the things we think we have learned about learning are the following. High aptitude biology students who use SemNet for one semester make significant gains in deep processing skills (Gorodetsky & Fisher, in press). High and low aptitude students make significant gains in their abilities to categorize and organize knowledge. Students who use SemNet to study a topic retrieve about twice as many ideas about that topic as students who study in other ways (Gorodetsky & Fisher, 1994). Collaborative net-building promotes significantly greater dialog, conversation, planning and polishing than working alone (Allen & Hoffman, in press). Peer review of student knowledge constructions seems to be fascinating and surprisingly valuable to students, in terms of conveying succinctly both possibilities for action (what can be done) and how to avoid pitfalls (what not to do).

Collaborative Use by Students

A new function allows different experts (or students) who have worked independently to merge their nets into a single net, thus bring their differing perspectives together into an integrated view. For example, in spring of 1993, science faculty from several different departments at the University of Eastern Kentucky each created a network on topics to be included in an integrated science course; they then merged their nets and reviewed the result, seeing clearly the major points of overlap and identifying potential points of confusion (McLaren, personal communication).

In fall 1993 and spring 1994, the merge feature was used regularly by students in a senior-level biology course for future elementary school teachers. The students have taken an introductory biology course years before and this follow-up course focuses on content and methods appropriate for teaching younger students biology. With regular use, students were able to work independently on different portions of the material and then to bring the individual pieces of the pie together into a whole. Students who owned their own computers and wanted to do their assignments at home found this to be especially useful. Working student groups found it advantageous to create a number of small, topic-specific nets (rather than one large one), and then to merge the nets to see the larger picture.

During the five years in which we have been experimenting with SemNet in this classroom, we have found that some strategies are much more successful than others in promoting learning. We summarize these below.

Students work in collaborative groups, typically made of four students each. It helps if the groups are constructed so as to include a reasonable balance of strengths in computer skills, biology knowledge, and English language skills, but a suitable range of such skills is generally available even when groups are formed by student selection. Collaboration has many well-documented benefits (e.g., Johnson, Johnson & Smith, 1991; Pea, 1992; Mazur, 1992). The ongoing dialog about biology that ensues combined with continuous meaning negotiation and spontaneous peer tutoring are particularly valuable, as are the friendships that form and the congenial environment that surrounds work in the computer lab.

Groups are monitored closely for the first few weeks, with adjustments made as necessary to assure smooth working relationships. A poor student-group match can be a nightmare for both the student and the group. One student was reduced to tears and tantrums several times each day because of animosities between her and her group, but after we paired her with another student having apparently similar work habits, she worked happily and productively all semester.

Introducing the idea of knowledge representation by demonstrating some concept maps and having students construct a paper-based concept map is a useful stepping stone to semantic networking. Mapping a cell is something our incoming biology students can do quite well. We then have students work through several tutorials on their own, including a Macintosh tutorial and a SemNet tutorial. Students are then asked to construct their family trees using SemNet. In this exercise students are representing a domain in which they are experts. Because the concepts (family members) and relations (parent/child, spouse, sibling, etc.) are well known to them, they can focus their attention on how the software works. Finally, students complete some paper and pencil exercises on identifying links between ideas and describing (naming) the relations in each direction.

These preliminaries are completed in the first week, after which students begin constructing knowledge nets to describe the biology they are learning. Their first net is on a fairly small topic and one that is reasonably easy to represent. The relations they will need are already created in their starter net along with many of the concepts they will need. Their task is to connect these fragments together.

Once the assignment is completed, each group reviews the nets created by at least four other groups. This review of one another's work is extremely instructive and interesting to the students. They learn a great deal about what to do and what not to do, and often want to revise their nets afterwards. This seems to work best when the review is not connected in any way with grading, but does provide feedback to the net authors. Reviews are especially important during the first third or so of the course.

The scaffolding for net-building given by the provision of initial concept and relation lists by the instructor is gradually reduced in successive assignments, so that by the fourth net or so each group is creating all of its own concepts and relations. Each week new net-building skills appropriate to the kinds of biology knowledge being learned are introduced; intermediate editing functions are demonstrated soon after initial net creation, followed by overviews, masking, jumping, merging, and saving a portion of a net, as appropriate. The instructor and tutors review nets regularly and provide as much specific feedback as possible to promote the optimum development of cognitive skills for thinking about and representing the biology being studied. Students are encouraged to integrate their experiential knowledge from the lab with more abstract ideas from text and syllabus.

One strategy to deepen student understanding is to require that students attend to key features of a topic. For example, in studying the human body, students must include the flow of materials through each organ system. Thus, for the digestive system, students show the flow of "foodstuff" from mouth to anus, adding each structure that the foodstuff passes through and identifying the key events that occur in each structure. They also illustrate the flow of bile from the liver and of enzymes from the pancreas. Attending to these details helps to ensure that students develop a working mental model. When the digestive system is merged with the circulatory system, connections are made (such as between the capillaries of the small intestine and the veins) that allow one to trace the flow of a sugar molecule from the digestive system to the brain.

Nets are usually graded in electronic form. It is possible to append notes to any concept or relation so as to provide feedback on-line. Sometimes nets are printed out and marked up on paper. In general they are graded like essays—by assessing the quality of the entire creation as a whole, not of each individual fact. Net-grading guides have been created for different assessment goals. Nets are worth about as much as tests in our course. Each midterm and final typically has both a written portion and a SemNet-based task.

Attaching Media-Rich Information

Conceptual understanding involves visual, aural, and experiential knowledge as well as semantic knowledge (Pea & Gomez, 1992). Sights and sounds are valuable for enriching conceptual representations. With a new SemNet function, users can attach documents created with other applications to nodes or links in their semantic networks. These documents can be created with any other application on the computer and so can include styled and formatted text, sounds of all types, and visual images including diagrams, sketches, drawings, animations, movies, photographs, electron micrographs, diagrams, charts, etc. Visual materials may be stored on hard disks, CD-ROM, or videodisc. The attachment itself includes a short description of the document's

relevance to the concept, so that the same document (e.g., a photomicrograph of a cell with a prominent nucleus) might be attached to several concepts for different reasons (e.g., to "photomicrograph", "cell", "eukaryotic cell", and "nucleus" with the latter perhaps described as "nucleus in context"). A related new feature allows the attachment of text, pictures, or documents to individual links between concepts, thus allowing attachment of illustrations of relationships between concepts (e.g., attaching the photomicrograph to the link expressing the fact that the nucleus is contained in a cell).

This new development makes possible the merging of an intelligently and systematically structured knowledge net with a plethora of multimedia. Semantic networks can provide a meaningful way to structure large collections of sounds and images and thus are useful for organizing libraries and other resource materials. They also provide access for people approaching a databank from many different areas of specialization—multiple world-views are allowed and encouraged. Given an existing network organizing a collection of documents, a user can superimpose a new organization on the collection simply by creating a new relationship and new links between concepts to represent the desired structure.

This feature is too new to have allowed full exploration of its use. However, it appears that by getting away from the linear and hierarchical structures usually imposed by other media-organization tools, a SemNet-based organizer supports browsing that follows the direction of the user's thoughts and interests, rather than the structure imposed by the creator of the collection.

Conclusion

Concept-mapping and semantic networks are a maturing methodology for enhancing student learning by giving them an external representation to focus their attention on, facilitating reflective thought and collaborative discussion resulting in increased understanding. New features of SemNet to support collaboration have produced significant improvements in motivation and learning by students. New features support the integration of other media types into conceptual nets further enrich students understanding of a topic and can also bring together disparate representations of the same concept into a central place.

References

Allen, B. S. & Hoffman, R. P. (in press). Varied support for constructive activity in hypermedia-based learning environments. In T. M. Duffy, D. Jonnasen, & J. Lowyck (Eds.), *Designing environments for constructive learning* (tentative title). Hillsdale, NJ: Lawrence Erlbaum Associates.

Allen, B. S., Kompella, J., Hoffman, R. P., & Sticht, T. G. (1991). *Computer-based mapping for curriculum development*. Technical Report. Available from B. S. Allen, Department of Educational Technology, San Diego State University, San Diego, Ca 92182.

Brody, M. (1990a). *Microcomputer-Based Knowledge Reconstruction in Preservice Elementary Science Education*. Paper presented at the Annual Meeting of the American Educational Research Association, Brody, April.

Brody, M. (1990b). *The relationship of basic scientific knowledge to the creation of multi-disciplinary schema.* Presented at the annual meeting of the American Educational Research Association, April.

Faletti, J., Fisher, K. M., Patterson, H. A., Thornton, R., & Lipson, J. (1991). SemNet, computer software for the Macintosh. Available from SemNet Research Group, 1043 University Ave., Suite 215, San Diego, CA, 92103. San Diego: SemNet Research Group.

Fisher, K. M., Faletti. J., Patterson, H. A., Thornton, R., Lipson, J., and Spring, C. (1990). Computer-based concept mapping: SemNet software—a tool for describing knowledge networks. *Journal of College Science Teaching, 19* (6), 347-352.

Fisher, K. M. & Goldberg, F. (1992) Unpublished progress report to NSF.

Fisher, K. M. & Thornton, R. M. (1987). *Impact of teaching explicit formal relations between concepts in biology*. Presented at the Annual Meeting of the American Educational Research Association, San Francisco, April.

Fisher, K. M. (1994). Unpublished data

Gordon, S. E. (in press). Conceptual graph structures: Knowledge representation using a constrained, domain-general syntax. In Fisher, K. M. & Kibby, M. R., *Knowledge Acquisition, Organization, & Use in Biology*, Berlin: Springer-Verlag.

Gorodetsky, M. & Fisher, K. M. (in press). Generating connections and learning. In Fisher, K. M. & Kibby, M. R., *Knowledge Acquisition, Organization, & Use in Biology*, Berlin: Springer-Verlag.
Gorodetsky, M., Fisher, K. M., Wyman, B. (1994). Generating Connections and Learning with SemNet, a Tool for Constructing Knowledge Networks. *Journal of Science Education and Technology*. In Press.
Heller, P., & Hollabaugh, M. (1992). Teaching problem solving through cooperative grouping. Part 2: Designing problems and structuring groups. *Am. J. Phys.*, *60* (7), 637-644.
Heller, P., Keith, R., & Anderson, S. (1992). Teaching problem solving through cooperative grouping. Part 1: Group versus individual problem solving. *Am. J. Phys.*, *60* (7), 627-636.
Hoffman, R. P. (1991). *Use of relational descriptors by experienced users of a computer-based semantic network*. Unpublished Master's Thesis, San Diego State University, San Diego.
Hofmann, J. & Welschselgartner, B. (1990). *Guide through the HECTOR (European Common Market Analysis) Framework of Reference*. Unpublished Technical Report . Fraunhofer-Institut für Arbeitswirtschaft und Organisation, Nobelstrasse 12 D-7000, Stuttgart 80, Germany.
Huppert, Jehuda. (1988). The use of the SemNet program in a heterogeneous biology classroom. Unpublished manuscript available from Jehuda Huppert, School of Education, Kibbutz Movement, Oranim, Tivon, 3691, Israel.
Jay, M., Alldredge, S., & Peters, F. (1990). *SemNet preliminary classroom study: 7th grade biology (ecology)*. Presented at the Annual Meeting of the American Educational Research Association, Boston, April.
Johnson, D., Johnson, R. & Smith, K. (1991). *Active Learning: Cooperation in the College Classroom*. Interaction Book Company, Edina, MN.
Kintsch, W., Miller, J. R., & Polson, P., eds. (1984). *Methods and tactics in cognitive science*. Hillsdale, NJ: Lawrence Erlbaum Associates.
McLaren, B. (1993). Personal Communication. Department of Biology, University of Eastern Kentucky, Richmond, KY.
Mazur, E. (1992). Peer Instruction—A User's Manual. Harvard University.
Norman, D. A., Rumelhart, D. E., & the LNR Research Group. (1975). *Explorations in cognition*. San Francisco: Freeman.
Pea, R. (1992). Augmenting the Discourse of Learning with Computer-based Learning Environments. In E. de Corte, M. Linn, H. Mandl & Verschaffel (Eds.), *Computer-based learning environments in problem-solving*. (NATO Series AS1 Series F). New York: Springer-Verlag.
Pea, R. & Gomez, L. (1992). Distributed Multimedia Learning Environments: Why and How? *Interactive Learning Environments*, **2**, 73-109.
Quillian, M. R. (1967). Word concepts: A theory and simulation of some basic semantic capabilities. *Behavioral Sciences*, 12, 410-430.
Quillian, M. R. (1968). Semantic meaning. In M. Minsky (Ed.), *Semantic information processing*. Cambridge, MA: MIT Press.
Schmeck, R. R., Ribich, F., & Ramanaiah, N. (1977). Development of a self-report inventory for assessing individual differences in learning processes. *Applied Psychological Measurement*, *1* (2), 413-431.
Schmeck, R. R. & Ribich, F. D. (1978). Construct validation of the Inventory of Learning Processes. *Applied Psychological Measurement*, 2 (4), 551-562.
Sowa, J. F. (1983). *Conceptual Structures: Information Processing in Mind and Machine*. Menlo Park, CA: Addison-Wesley.

A New Knowledge Representation Scheme For The Subject Of Physics

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Abstract: Discussed in this paper is a new knowledge base representation scheme for the subject of physics. This new scheme is called the situational based architecture and is presently employed by a computer program call Pro Solv, an expert system for physics problems. The architecture is explained and contrasted to the traditional method of organizing physical knowledge. The steps involved in setting up and solving problems within this scheme are detailed as is the search algorithm employed by Pro Solv. The benefits of this representation are discussed as well as the generality of this model in terms of its ability to cover all problems. Finally a justification for this model is given based on the experimental method for acquiring new physics knowledge.

Intelligent technological systems which enable individuals to solve complex problems are becoming an increasingly important tool to scientists, engineers and students. Such systems relegate to the technical device many of the time consuming and tedious chores which would otherwise be performed by hand. This technology allows the organization of problem solving tasks into higher levels or larger chunks, which is an essential component of developing problem solving skills.

Systems of these types have existed for many years, most notably in the field of mathematics. Calculators have allowed individuals to perform far more computations by relieving them of the tedious aspects of subtraction, multiplication and division. Math software such as Mathematica, Maple and Macsyma provide similar benefits in more advanced areas of mathematics.

Intelligent problem solving aids of this type, however, have been virtually nonexistent in most areas of physics and the related areas of technology and engineering. One such tool, however, recently introduced is called Pro Solv. Pro Solv is an expert system for problems encountered in the subjects of mechanics, electricity, magnetism and optics. Pro Solv's design is unique in that it employs a novel approach to the organization and manipulation of information within its knowledge base. The structure and benefits of this organization are the focus of this presentation.

COGNITIVE ELEMENTS OF PROBLEM SOLVING

General problem solving systems involve two types of search, knowledge search and problem search. Problem search takes place in a problem space consisting of an initial state, a goal state, the problem space operators and all the possible intermediate states which the operators can produce. Problem search is the process of finding a sequence of operators that will reach the goal state. Typical methods of problem search include depth first search and breadth first search.

In a system covering a wide base of information, knowledge search is also required. Knowledge search is the search for the knowledge which will be included in the problem space and which will guide the problem search. Of particular importance to this discussion is the process of finding the operators which belong in the problem space.

In a physics problem, the initial state is the set of given information in the problem. The goal state can take different forms but is, perhaps, most often of the form $x = ?$. The operators are the principles of physics and mathematics. Problem search is the process of applying the principles and mathematical operations in order to calculate the unknown variable x. Knowledge search in a physics problem is the process of establishing the operators (principles) which are relevant to solving the problem.

Perhaps the most important aspect of problem solving is how information is organized and represented in the knowledge base. This organization has a significant impact on the efficiency of the problem solving system, whether a computer or a human. In particular, it affects the efficiency of both knowledge search and problem search.

THE TRADITIONAL METHOD OF ORGANIZING PHYSICS KNOWLEDGE

The method of organization of physics material in traditional textbooks and courses is considerably different from that within Pro Solv. Most textbooks organize the material into subjects first and then breakdown the material into several sub-topics. Following is a listing of topics from Part I Mechanics of Raymond Serway's *Physics for Scientists and Engineers:*

Topic	What the topic represents
Vectors	Physical Object
Motion In One Dimension	Situation
The Laws of Motion	Principles
Circular Motion	Situation
Work and Energy	Physical Concepts

This organization is reasonable for the introduction of principles and concepts of physics. It follows a pedogogically sound tutorial presentation. This organization of the material, however, is not very efficient or effective when the task is that of solving problems. The reason for this inefficiency will be discussed later, but is in part due to the inconsistency in what each topic actually represents. The difficulty experienced by many students of introductory physics is also a strong indication of the failing of the traditional presentation of physics material.

THE SITUATIONAL BASED ARCHITECTURE

Situation Definition

The organization upon which Pro Solv is designed is a situational based architecture. In this representation scheme, principles of physics are organized into a number of general classes of situations. A situation is a general description of the state of some set of physical objects. Listed below is a representative sample of situations encountered in the mechanics section of an introductory course in physics.

Mechanics

- Object Moving With Constant Velocity
- Object With Constant Acceleration (One Dimension)
- Object With Constant Acceleration (Two Dimensions)
- Single Force On An Object (One Dimension)
- Single Force On An Object (Two Dimensions)
- Two Forces Applied To An Object (Two Dimensions)
- Object In A Constant Gravitational Field

Constituent Entities and Their Attributes

A situation is composed of its constituent entities (physical objects) and the defining constraints which apply to these entities. A physical object is any entity that may exist in a situation. Examples are a particle, a projectile, a charge, a force, a vector, an amount of energy, and time.

Each physical object is described by one or more attributes which define its specific state. The physical objects and their attributes for "An object moving with constant acceleration" are listed below.

1. **Object:**
   - d_i - The initial position of the object (m)
   - d_f - The final position of the object (m)
   - Δd - The total displacement of the object (m)
   - v_i - The initial velocity of the object (m/s)
   - v_f - The final velocity of the object (m/s)
   - v_{ave} - The average velocity of the object (m/s)
   - a - The acceleration of the object (m/s^2)

2. **Time:**
   - t_i - The initial time (s)
   - t_f - The final time (s)
   - Δt - The total length of time the object was moving (s)

To define a specific situation one needs only to give values to the known attributes of the physical objects within the situation class. Lets take a dragster as an example. A dragster moves in a straight line and for simplicity sake we will assume with constant acceleration. This specific situation is therefore a member of the class of situations "An object moving with constant acceleration". The initial velocity of the dragster is 0, and the displacement of the dragster is .25 miles.

$$v_i = 0$$
$$\Delta d = .25 \text{ miles}$$

Principles of a Situation

Each situation class owns an associated set of physical principles which govern the relationships between the attributes of each physical object. For example, the kinematic equations associated with constantly accelerated motion belong to the situation of "An object moving with constant acceleration" and describe the relationships between the object's velocity, acceleration and position as well as time traveled.

$$\Delta d = \tfrac{1}{2}a\Delta t^2 + v_i\Delta t$$
$$v_f^2 + v_i^2 = 2a\Delta d$$
$$a = \frac{(v_f - v_i)}{\Delta t}$$
$$v_{ave} = \frac{(v_f - v_i)}{2}\ , \quad \Delta d = v_{ave}\Delta t$$
$$\Delta d = d_f - d_i$$
$$\Delta t = t_f - t_i$$

General Problem Solving Process

The general process for solving a problem within the situational based architecture requires following these steps:

1) Choose the proper situation or situations
2) Describe the values of the known attributes
3) Define the goal, or unknown to be calculated
4) Engage the problem search algorithm which will apply the set of principles

BENEFITS OF THE SITUATIONAL BASED ARCHITECTURE

The Search Algorithm

In a typical problem, the number of principles required to reach the goal state is usually less than 5. If a depth first search algorithm is employed in this problem space. the number of possible solution paths is

5! = 120. This number represents a worst case figure. In most cases, only a small percentage of the total number of paths need actually be searched.

The situational based architecture ensures that the number of problem space operators is kept close to the number actually needed to solve the problem. This point is critical in reducing the time and energy consumed by the problem search.

Pro Solv's search algorithm employs a depth first search strategy. There are very few heuristics involved to the limiting of problem space operators. Typical problems encountered at an introductory level can be solved within a few seconds.

Establishing The Search Space Operators

Perhaps the most critical step in solving physics problems, is performing the knowledge search. This is where the traditional organization of physics material is particularly deficient. When principles are organized in the traditional fashion, there is no efficient method for establishing the problem space operators. One can fairly easily identify the applicable subjects and perhaps even one level of sub-topic. This, however, still leaves one with a potentially large number of principles. One must now examine the limitations of each principle to discover if it even applies to the problem at hand.

Serway advices in the introductory remarks to his textbook that, "I often find that students fail to recognize the limitations of certain formulas or physical laws in a particular situation. It is very important that you understand and remember the assumptions which underlie a particular theory or formalism. For example, certain equations in kinematics apply only to a particle moving with constant acceleration. These equations are not valid for situations in which the acceleration is not constant, such as the motion of an object connected to a spring..."

This quote points out both the major problem with the traditional presentation of physics and introduces the rationalization behind the situational based architecture. Every physical principle is applicable only under a set of limiting conditions (which define a general situation class). Before any principle can be included in the problem space, it must be determined whether or not the specific problem is a member of the situation class to which the principle applies. One must therefore first understand the situation described in the problem, then understand the situation to which each principle applies and see if the two situations are identical. If they are, then the principle may be useful. This process must be done for every principle to be considered for inclusion into the problem space. This is not an efficient process, nor one easily carried out by beginning students.

Why not instead organize the principles by situation in the first place. Some principles will appear more than once, like energy conservation, but this is not a problem. This organization would eliminate a time consuming, difficult and frustrating task.

Organizing the physical principles into situation classes with their own set of applicable principles, virtually eliminates the problem of finding relevant principles. Establishing the operators for the search space is reduced to mapping the real world problem to one or more of the general situation classes available. Once a situation class has been identified, the applicable principles are immediately known. This mapping is a far easier task than the process required with the traditional organization of physics principles.

Mapping The Known Quantities To Equation Variables

An additional difficulty with physics problem solving is mapping the known quantities to the variables within an equation. Within the traditional organization of physics material this process is somewhat creative. There is no straight-forward method for performing this mapping. Within the situational based architecture, the specific meaning of each variable within an equation can be clearly identified and can unambiguously be correlated to one of the attributes of the situation's constituent entities.

Relatively Easily Encoded In A Computer

Perhaps the most significant benefit to the situational based architecture is that it lends itself very nicely to encoding within a computer. The structure is consistent from subject to subject and from topic to

topic. Thus, as a student or engineer calculates a problem within mechanics. the approach and user interface will not change as he moves to a problem within optics. The fact that the operators (principles) are identified by choice of the situation also eliminates the process of finding the proper operators. Consequently, the problem search algorithm is very manageable. The fact that the variables within equations are easily mapped to the known information also eliminates a serious problem in the design of a general problem solving tool.

GENERALITY OF THE SITUATIONAL BASED ARCHITECTURE

An important question with regard to the situational based architecture is its generality. Is it sufficiently general to enable description of all physical situations. The answer is yes and can be supported in two ways. Both methods have their advantages and disadvantages.

The number of situations which can be included in the grand knowledge base of the system is theoretically unlimited. Thus, for any new situation, a situation class could be defined and included in the list of situations. Thus, shear numbers could account for all situations. For example, if a new electronic circuit is constructed about which information is wished to be calculated, a general situation could be constructed which is identical in structure to the new circuit. The entities of the situation would be the various circuit elements with the attributes of resistance and capacitance.

The positive feature of this strategy is that the resulting situation is highly customized for the engineer's needs. The negative aspect of this strategy is that it results in a large number of situations, and may require a degree of search on the part of the engineer. This search, could of course, be facilitated by certain features in the software or in an index. An additional negative is that while this strategy offers complete generality to the developer of situations, it does not offer complete generality to the user of the software. To offer complete generality to the user, another method must be employed.

A more efficient method of accounting for all possible problems is to encode a set of fundamental situations which can be used to compose all complex situations. The user could then construct any arbitrary situation by combining two or more of the fundamental situations. For example, a rocket ship would be a complex situation composed of "constant force applied to an object" and "an object moving with constant velocity".

EMPIRICAL JUSTIFICATION FOR THE SITUATIONAL BASED ARCHITECTURE

A simple justification for the situational based architecture can be found by examining the method of developing physical laws in the first place. Experimental physicists examine nature by setting up experiments under certain well defined conditions. They observe the relationships among the various constituent elements of the experiment and determine the equations and laws which relate the attributes of these elements.

The laws of physics discovered through experimentation can only be assumed to be true under the general set of conditions defined by that experiment. This general set of conditions defines a situation class. Therefore, each physical law has a general situation to which it applies. This situation may be fundamental and emody other situations. For example, the principle of energy conservation is applicable to the situation of any closed system which encompasses many other situations. It could be argued, then, that the situational based architecture is the only one which experimental evidence supports.

References

Newell, A. (1990). *Unified Theories of Cognition*. Cambridge, MA: Harvard University Press

Serway, R (1986). *Physics for Scientists & Engineers Second Edition*. Philadelphia, PA: Saunders College Publishing

Tanimoto, S. L. (1987) *The Elements of Artificial Intelligence*. Rockville, MD: Computer Science Press, Inc.

A Research Study of Teachers' Beliefs About Calculator Use

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Abstract: Previously, Fleener (1994) noted mathematics teachers were divided on whether students should master a concept before using calculators. This paper examines teachers' attitudes and beliefs about calculator use from a contextual perspective (Kay, 1992). Indicators of philosophical orientation and contextual perspective are developed by identifying Habermasian interest categories. Results of 231 surveys suggest teachers have differing philosophical orientations related to their stated beliefs about the need for conceptual understanding before using calculators. Inservice efforts must address these differences in philosophical perspectives as teachers struggle to make sense of the calculator reform movement.

Much of the literature on teacher change emphasizes the need for on-going staff development opportunities and support (Fullan, 1991; Strudler, 1991). Teacher beliefs are important when trying to understand the change process as beliefs guide action, instructional decisions and practices in the classroom (Clark & Peterson, 1986; Ernest, 1989; Fennema, 1989; Fennema & Franke, 1992; Munby 1984; Thompson, 1992; Thompson, 1984) and are related to the success of staff development efforts (Peterson, Fennema, Carpenter, & Loef, 1987; Richardson, Anders, Tidwell, & Lloyd, 1991).

This study examines 231 teachers' beliefs about the use of calculators in mathematics instruction to determine whether patterns of belief statements reveal differing philosophical orientations to knowledge acquisition. Responses to conceptual mastery items on the Attitude Instrument for Mathematics and Applied Technology-version II (AIM-AT-II) (see Fleener, 1994) provide data for evaluating characteristics of three groups of teachers divided on the issue of whether students should be allowed to use calculators before they had mastered the concept. Guiding questions for this study are:

1. Are classroom teachers' opinions divided on the mastery issue revealing differing perspectives toward calculator use in the classroom?
2. If different perspectives of calculator use exist, are these differences indicative of philosophical orientations as expressed through Habermasian interests?

Background

In a review of teacher belief research, Pajares (1992) advocated the need for a clear definition of beliefs separate from the related constructs of knowledge, attitudes, and feelings. Kay (1992) favored a contextual framework for understanding complex attitudes toward technology. Responding to efforts to define beliefs as a distinct construct, separate from knowledge, attitudes and feelings, Kay argued beliefs, knowledge, attitudes, feelings and actions are intertwined within a contextual framework which includes internal as well as external/social factors. Based on the work of Bereiter (1991), Kay defined "[a]contextual module is a kind of learning environment which synthesizes declarative knowledge, procedural knowledge, goal structures, problem models, affect, self-concept, and code of conduct" (p. 164). According to Kay, the contextual approach allows for a more "global and interactive understanding" of complex systems by "focusing on a number of influences simultaneously" (p. 164).

Similarly, in this study, calculator use belief structures will be interpreted broadly as part of a

complex, dynamic, contextually related framework with interactions among beliefs, attitudes, knowledge, and action in a social environment. Underlying philosophical approaches guiding the complex learning-teaching environment will be identified by Habermasian interest categories and related to contextual belief frameworks about using calculators.

Habermas described three fundamental human interests (control, hermeneutic, and emancipatory) related to the empirical, pragmatic and critical philosophical approaches to knowledge (Habermas, 1971). Habermas' work addresses the relationship between theory/knowledge and practice as fundamental human interests gird knowledge and idealogy as determiners of action (Grundy, 1987). As explained by Ewert (1991), "different human interests require different forms of knowledge that require different scientific methodologies (processes of knowing) based on different ...forms of rationality" (p. 347).

Methods

Procedures

The 29-item AIM-AT-II was adapted from the AIM-AT (Fleener, 1994) to focus on teacher beliefs about how calculators should be used in mathematics instruction. Internal and external reliability of the AIM-AT were addressed in an earlier study (Fleener, 1994). Internal reliability for this population on the AIM-AT-II was .67. Likert-type forced response options on AIM-AT-II items were Strongly Agree=4, Agree=3, Disagree=2, and Strongly Disagree=1.

During October and November, 1993, 231 Oklahoma teachers participated in graphing calculator workshops coordinated through the University of Oklahoma, area Professional Development Centers and individual schools and school systems.

Analyses

Mastery items 7 and 17 of the AIM-AT-II were used to form three groups. Teachers who agreed with item 7 (Students should not be allowed to use calculators until they have mastered the concept) and disagreed with item 17 (Students should be allowed to use calculators even before they understand the underlying concepts) formed the MASTERY=YES group indicating their belief that students should have conceptual mastery before being allowed to use a calculator. Teachers who disagreed with item 7 and agreed with item 17 formed the MASTERY=NO category and teachers who provided inconsistent responses (either agreeing or disagreeing with both statements) formed the third group, MASTERY=MAYBE. Two teachers who could not be classified were eliminated from the original pool of 233 respondents.

Analysis of variance (ANOVA) was used to determine whether mastery groups differed with respect to their responses on AIM-AT-II items in order to answer research question 1. If significance was found, Scheffe multiple comparisons was used to determine which groups differed significantly at the .05 level.

Items on which mastery group responses differed significantly were read by three educational researchers familiar with Habermasian human interests categories and separated into CONTROL, HERMENEUTIC and EMANCIPATORY categories. Within the CONTROL category, items were considered positively or negatively oriented depending upon whether agreement or disagreement indicated an interest in control. Agreement with positively scored and disagreement with negatively scored CONTROL items indicated a controlling interest. The HERMENEUTIC/UNDERSTANDING items were considered positive if agreement indicated positive attitudes toward calculator use for increasing understanding while disagreement on negatively scored items indicated a positive attitude toward calculator use for increasing understanding. EMANCIPATORY items were scored positively or negatively depending upon whether agreement or disagreement indicated a belief that calculator use is liberating, exciting, motivational, or serves a social good. Several items suggested overlapping interests in understanding and emancipation and were placed in both categories. Similar to the approach used by Schmidt and Callahan in their research on teachers' and principals' beliefs regarding calculators (1992), strength of response was summarized for the YES and NO groups according to the percentage of agreement (or disagreement) with items in each Habermasian category (over 80%=1,60-79%=2,40-59%=3,20-39%=4,under 20%=5). For example, agreement on positively scored and disagreement on negatively scored CONTROL items, as indicated by an average strength of response score of 1 or 2, indicated a control interest. YES and NO

group differences with respect to CONTROL, HERMENEUTIC, and EMANCIPATORY human interest categories were compared to determine whether differences existed in philosophical/contextual orientations between the two mastery groups.

Results and Discussion

Question 1: Are classroom teachers' opinions divided on the mastery issue revealing differing perspectives toward calculator use in the classroom?

Using a one factor ANOVA comparing the three mastery groups (YES, NO, MAYBE) to responses to AIM-AT-II items, significant group differences were found on 21 of the 27 AIM-AT-II items (excluding items 7 and 17 which were used to define the mastery groups) with three items revealing differences among all three groups. Because so many items revealed group differences, the existence of distinct groups with differing belief systems is indicated. Only three items revealed group differences among all mastery groups, however, which suggests there are two distinct groups with a third group transitional or in flux between the two extremes. This observation is consistent with Darling-Hammond's assertion (1993) that mathematics education reform efforts are guided by two very different and at times opposing theories.

Multiple comparisons analysis revealed differences among all three groups on items 6 ($F(2,217)=23.86, p<.01$), 19 ($F(2,218)=42.27, p<.01$) and 26 ($F(2,219)=22.24, p<.01$). While 62% of the MASTERY=YES group agreed with item 6 (Students understand math better if they solve problems using paper and pencil), 87% of the MASTERY=NO and 62% of the MASTERY=MAYBE groups disagreed. Similarly, 82% of the MASTERY=YES group agreed with item 19 (Calculators should not be used until students know their arithmetic facts), while 81% of the MASTERY=NO group disagreed with that statement. The MASTERY=MAYBE group was mixed as 51.5% agreed and 48.5% disagreed with statement 19. On item 26, (Students should learn the paper and pencil long division algorithm before using the calculator to divide), 88% of the MASTERY=YES group and 69.5% of the MASTERY=MAYBE group agreed while 58.5% of the MASTERY=NO group disagreed with that statement. The MASTERY=MAYBE group fell between the other two groups on each of these items supporting the continuum hypothesis with the MAYBE group in transition between the YES and NO extremes.

On items where there was a statistically significant difference between the MASTERY=YES and MASTERY=NO groups, the MASTERY=MAYBE group fell in between the YES and NO group means on every item except item 4, further suggesting the MAYBE group is a transitional group between the YES and NO groups. The majority of all groups disagreed with item 4 (When solving problems with calculators, students don't need to show their work on paper), although the YES and MAYBE groups were more polarized in their rejection of that statement with 81% and 84% disagreeing, respectively, while only 67% of the NO group disagreed with item 4.

On every item where there was a statistically significant difference between YES and NO groups but not between YES-MAYBE and NO-MAYBE comparisons, there was consensus (agreement or disagreement) among the groups. Differences on items 3, 11, 12, 16, 20, 21, 22, and 24 indicate a strength of commitment rather than differences of opinions. For example, on item 12 (Using calculators will cause students to lose basic computational skills), 62% of the YES, 75% of the MAYBE, and 79% of the NO groups disagreed with the statement. Similarly, on statement 24 (Students can gain understanding of computational procedures by using calculators), 81% of the YES, 88% of the MAYBE, and 94% of the NO groups agreed.

Question 2: If different perspectives of calculator use exist, are these differences indicative of philosophical orientations as expressed through Habermasian interests?

The results of the ANOVA show there were at least two distinct belief systems revealed by YES and NO mastery groups. In order to determine philosophical differences among groups, categorization of AIM-AT-II items according to CONTROL, HERMENEUTIC, or EMANCIPATORY interests was used to reveal patterns of systematic responses. (See Table 1.)

Both YES and NO mastery groups indicate some interest in control as seen in Table 1. On items 4 and 20, where both groups express strong controlling interests, statistical differences between YES and NO

groups suggest these groups differ with regard to the intensity of their responses. On item 4, the mean score of the YES group was 1.883indicating strong disagreement while the mean score of the NO group was 2.275, a more moderate response. Likewise, responses to item 20 suggest the YES group more strongly agrees with that statement with a mean response of 3.345while the NO group is less committed with a mean score of 2.981. The NO group did not display a higher degree of control on any of the CONTROL items while the YES group clearly indicated an interest in control on 8 of the 10 items (including items 4 and 20).

Table 1
AIM-AT-II items by Habermasian categories

ITEM	INTEREST	SCORE (Positive/Negative)	INTENSITY YES GP	INTENSITY NO GP	PREDOMINANT GROUP	YES/NO CONTINUUM (MEAN)	EXTREME GROUP
1	Control	Negative	3	4	Neither	(Y=2.51,N=3.226)	M-YES
4	Control	Negative	1	2	Both	(Y=1.883,N=2.275)	M-YES
7	Control	Positive	1	5	M-YES	(N=1.698,Y=3.379)	M-YES
8	Control	Negative	2	4	M-YES	(Y=2.039,N=2.736)	M-YES
10	Control	Positive	4	5	Neither	(N=1.654,Y=2.382)	M-YES
11	Control	Positive	4	5	Neither	(N=1.736,Y=2.243)	M-YES
17	Control	Negative	1	5	M-YES	(Y=1.718,N=3.226)	M-YES
19	Control	Positive	1	5	M-YES	(N=1.981,Y=3.049)	M-YES
20	Control	Positive	1	5	M-YES	(N=2.981,Y=3.345)	M-YES
22	Control	Positive	4	5	Neither	(N=1.538,Y=2.01)	M-YES
26	Control	Positive	1	3	M-YES	(N=2.415,Y=3.175)	M-YES
2	Hermeneutic	Negative	3	2	M-NO	(N=1.925,Y=2.563)	M-NO
6	Hermeneutic	Negative	4	1	M-NO	(N=1.981,Y=2.75)	M-NO
12	Hermeneutic	Negative	2	2	Both	(N=1.906,Y=2.396)	M-NO
14	Hermeneutic	Positive	1	1	Both	(Y=3.05,N=3.442)	M-NO
15	Hermeneutic	Negative	3	1	M-NO	(N=1.885,Y=2.392)	M-NO
16	Hermeneutic	Positive	1	1	Both	(Y=3.291,N=3.66)	M-NO
21	Hermeneutic	Positive	1	1	Both	(Y=3.039,N=3.472)	M-NO
24	Hermeneutic	Positive	1	1	Both	(Y=2.835,N=3.302)	M-NO
1	Emancipatory	Positive	3	2	M-NO	(Y=2.51,N=3.226)	M-NO
3	Emancipatory	Positive	1	1	Both	(Y=3.359,N=3.66)	M-NO
4	Emancipatory	Positive	5	4	Neither	(Y=1.883,N=2.275)	M-NO
8	Emancipatory	Positive	4	2	M-NO	(Y=2.039,N=2.736)	M-NO
9	Emancipatory	Positive	1	1	Both	(Y=3.136,N=3.585)	M-NO
10	Emancipatory	Negative	2	1	Both	(N=1.654,Y=2.382)	M-NO
14	Emancipatory	Positive	2	1	Both	(Y=3.05,N=3.442)	M-NO
16	Emancipatory	Positive	1	1	Both	(Y=3.291,N=3.66)	M-NO
19	Emancipatory	Negative	5	1	M-NO	(N=1.981,Y=3.049)	M-NO
20	Emancipatory	Negative	5	5	Neither	(N=2.981,Y=3.345)	M-NO
22	Emancipatory	Negative	2	1	Both	(N=1.538,Y=2.01)	M-NO
29	Emancipatory	Negative	4	2	M-NO	(N=2.075,Y=2.745)	M-NO

Similarly, both YES and NO groups exhibited some degree of hermeneutic and emancipatory interests. An examination of mean scores, however, indicates the NO group scored significantly higher on positively scored items and lower on negatively scored items than did the YES group on all hermeneutic items. (See Table 1.) Thus, although both groups show an interest in understanding on 5 of the 8 hermeneutic/understanding items, the NO group scored significantly higher on positively scored items or lower on negatively scored items than did the YES group as determined by results of ANOVAs. This indicates the NO group expresses a stronger hermeneutical interest orientation than the YES group.

Similarly, the NO group exhibited a stronger emancipatory orientation than the YES group on every

EMANCIPATORY item, even though both groups indicate interest in emancipation on 6 of the 12 EMANCIPATORY items. On no EMANCIPATORY item did the YES group have a mean score higher (or lower for negatively scored items) than the NO group.

Therefore, YES and NO groups do differ in philosophical orientation as expressed through fundamental human interests. The YES group exhibited a greater interest in control while the NO group was more pragmatic. The predominance of the NO group on items from the HERMENEUTIC and EMANCIPATORY categories suggests the NO group is more critical with regard to beliefs about calculator use.

Significance

The relationship between philosophical orientation (or ways of knowing) and beliefs as they relate to teacher change is lightly researched (Richardson, Anders, Tidwell, & Lloyd, 1991; Wood, Cobb, Yackel, 1991). "People's interests in how technology should be used in schools often parallel their basic theory of how learning best occurs" (Strudler, 1993, p. 8). Lieberman and McLaughlin (1992) noted traditional in-service attempts often fail to affect permanent change. Many researchers discuss the central role prior values, beliefs, attitudes, and knowledge play in reform efforts (Hord, Rutherford, Huling-Austin, & Hall, 1987) but do not consider teachers' personal philosophies nor the contextual framework, including social norms, of which belief structures form a part (Kay, 1992).

Understanding personal theory and the connection/relation between ideas, beliefs, knowledge, and practice is important as Smyth (1992) contends:

> we need to regard the views we hold about teaching not as idiosyncratic preferences, but rather as the product of deeply entrenched cultural norms of which we may not even be aware. ...Teaching becomes less of an isolated set of technical procedures and more of a historical expression of shaped values about what is considered to be important about the nature of the educative act (pp. 298-299).

This study shows efforts to change teacher practice require critical examination of the teachers' contextual frameworks as expressed through Habermasian interests. Incorporating technology in the teaching of mathematics may require a reconstitution of beliefs about teaching and learning, and critical examination of existing beliefs is especially important before teachers adopt calculators in mathematics instruction. Complex systems of belief about using calculators delineate contextual frames for understanding why teachers react differently to staff development opportunities. Inservice efforts must address these fundamental differences as teachers struggle to make sense of the calculator reform movement.

References

Bereiter, C. (1991). Aspects of educational learning theory. *Review of Educational Research*, *60*(4), 603-624.

Clark, C.M. & Peterson, P.L. (1986). Teachers' thought processes. In M.W. Wittrock (Ed.), *Handbook of research on teaching* (3rd edition) (pp. 255-296). New York: Macmillan.

Darling-Hammond, L.D. (1993). Reframing the school reform agenda: Developing capacity for school transformation. *Phi Delta Kappan*, *74*(10), 753-761.

Ernest, P. (1989). The knowledge, beliefs and attitudes of the mathematics teacher: A model. *Journal of Education for Teaching*, *15*(1), 13-33.

Ewert, G.D. (1991). Habermas and education: A comprehensive overview of the influence of Habermas in educational literature. *Review of Educational Research*, *61*(3), 345-378.

Fennema, E. (1989). The study of affect and mathematics: A proposed generic model for research. In D.B. McLeod and V.M. Adams (Eds.), *Affect and Mathematical Problem Solving*. New York: Springer-Verlag, pp. 205-219.

Fennema, E. & Franke, M.L. (1992). Teachers' knowledge and decision making. In D.A. Grouws (Ed.), *Handbook of research on mathematics teaching and learning* (pp. 147-164). New York: Macmillan.

Fleener, M.J. (1994). Is Experience Enough?: A Survey of Mathematics Teachers' Philosophies of Calculator Use. In Carey, D. Carey, R., Willis, D.A., Willis, J. (Eds.) *Technology and Teacher Education*

Annual: 1994. Charlottesville, VA: Association for the Advancement of Computing in Education.
Fullan, M. (1991). *The new meaning of educational change*. New York: Teachers College Press.
Grundy, S. (1987). *Curriculum Product or Praxis*. New York: Falmer Press.
Habermas, J. (1971). *Towards a Rational Society*. London: Heinemann Press.
Hord, S.M, Rutherford, W.L., Huling-Austin, L. & Hall, G.E. (1987). *Taking Charge of Change*. Alexandria, VA: ASCD
Kay, R.H. (1992). Understanding gender differences in computer attitudes, aptitude, and use: An invitation to build theory. *Journal of Research on Computing in Education*, *25*(2), 159-171.
Lieberman, A. & McLaughlin, M.W. (1992). Networks for educational change: Powerful and problematic. *Phi Delta Kappan*, *73*(9), pp. 673-677.
Munby, H. (1984). A qualitative approach to the study of a teacher's beliefs. *Journal of Research in Science Teaching*, *21*, 27-38.
Pajares, M.F. (1992). Teachers' beliefs and educational research: Cleaning up a messy construct. *Review of Educational Research*, *62*(3), 307-332.
Peterson, P.L., Fennema, E., Carpenter, T.P. & Loef, M. (1987). *Teachers' pedagogical content beliefs in mathematics* (Report No. MDR-8550236). Washington, DC: National Science Foundation.
Richardson, V., Anders, P., Tidwell, D., & Lloyd, C. (1991). The relationship between teachers' beliefs and practices in reading comprehension instruction. *American Educational Research Journal*, *28*(3), 559-586.
Schmidt, M.E. & Callahan, L.G. (1992). Teachers' and principals' beliefs regarding calculators in elementary mathematics. *Focus on Learning Problems in Mathematics*, *14*(4), 17-29.
Smyth, J. (1992). Teachers' work and the politic of reflection. *American Educational Research Journal*, *29*(2), pp. 267-300 (Summer).
Strudler, N.B. (1993). Staff development and technology: A position paper. *Journal of Computing in Teacher Education*, *9*(4), 8-9.
Strudler, N.B. (1991). Education faculty as change agents: Strategies for integrating computers into teacher education programs. *Journal of Computing in Teacher Education*, *8*(2), 5-8.
Thompson, A. (1992). Teachers' beliefs and conceptions: A synthesis of the research. In D.A. Grouws (Ed.), *Handbook of research on mathematics teaching and learning* (pp. 127-146) New York: Macmillan.
Thompson, A.G. (1984). The relationships of teachers' conceptions of mathematics teaching to instructional practice. *Educational Studies in Mathematics*, *15*, 105-127.
Wood, T., Cobb, P., Yackel, E. (1991). Change in teaching mathematics: A case study. *American Educational Research Journal*, *28*(3), 587-616.

AI Based Tools in Teaching/Learning Arithmetic

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Abstract: Two approaches can be followed to develop Knowledge based Systems devoted to arithmetic. On the one hand, systems can be designed to focus on arithmetic word problems, thus concentrating on the cognitive problems underlying the comprehension of the text, the organisation of information and the translation of the text into a formal language. On the other hand, systems are centered on the acquisition of arithmetical skills, thus focusing on the cognitive analysis of students' performance in doing computations and on the teaching strategies employed to improve that performance.

In the following, we shall focus on the second approach. In particular, we shall discuss the work we are carrying out and frame it in the context of the research in the field.

Introduction

Based on the authors' cognitive views, KBS oriented to the teaching/learning of arithmetic have been designed with different aims and approaches (Nwana, H.J., 1993) (Wenger, E., 1987). Some focus on the analysis of students' errors, in order to build a model of their behaviour, while others examine teachers' diagnosis of students' performance and approach to remediation. Other authors use systems as workbenches to analyse methods which adapt tutoring to students' behaviour in order to increase the accuracy in the employment of strategies (Beishuizen, J. & Felix, E., 1991). Finally, we find proposals aimed at endowing learning environments with a measure of teaching capability, on the basis of both general hypotheses on learning and the diagnosis of students' performance.

Two paradigmatic examples are BUGGY and WEST. BUGGY is a diagnostic system, applied to arithmetical sums and substractions, working on the idea that, in problems requiring the application of procedural skills, errors are due to correct applications of incorrect procedures. The diagnosis is directed by a detailed hierarchy of abilities employed to perform operations. On the basis of the BUGGY model, a system has been devised to train teachers in analyzing students' errors.

WEST (Burton, R.R. 1982), a system aimed at being used in teaching/learning arithmetic expressions, is founded on the discovery based theory. According to it, the student co-operates with the teacher in investigating the domain of instruction. The theory assumes a constructivist position, that is new knowledge is built by the student out of a previous one. WEST is a coaching system centered on a game. The intervention of the tutor aims at giving the student additional information in order to transform non-constructive bugs into constructive ones. The hints of the tutor are shown in form of examples; a mechanism aimed at ensuring that these hints are both "relevant" and "memorable" has been implemented.

Among the most recent realisations we recall SUMIT (Nicolson, R. I., 1992), PCMATH (Al-Kaudurie, O. & Morgan, S., 1989), and the work of Beishuzein and Felix (Beishuizen, J. & Felix, E. 1991). SUMIT assists students in respect of the four operations, designed to meet the requirements of classroom arithmetic teachers. The system gives adaptive help and diagnoses misconceptions. PCMATH, which uses a bug catalog to diagnose errors, helps students improve arithmetic skills by giving animated representations of arithmetical processes. Moreover, different strategies of teaching are embedded in the system. Beishuzein and Felix work towards the building of a learner-oriented model of expertise in order to guide tutoring. They use the notion of genetic graph proposed by (Goldstein, I.P., 1982).

From the analysis of the systems so far developed it can be observed that their majority analyses arithmetic skills only by taking into account problems involving numbers. In our opinion, such problems

represent only one aspect of arithmetic knowledge, as they do not permit to establish if students possess any declarative arithmetic knowledge. In order to overcome this difficulty, we built a system, called ENIGMA, aimed at guiding students to perform arithmetic operations by using both a procedural and a declarative approach. A prototype version of the system is running on McIntoshII. The prototype has been experimented on a limited number of pupils aged 9-10.

The pedagogical choices which guided the design of the system are briefly discussed below. For a technical description we refer to (Forcheri, P. & Molfino, M.T., 1991).

The Enigma System

In accordance with the above ideas, our system aims at making students compute starting from arithmetical expressions expressed in symbolic form. This activity, due to the age of the intended user, is carried out in a game environment. More precisely, ENIGMA is centered on the following cryptoarithmetical game: to find out what digits should be substituted to the symbols in a symbolic relation, such as, for example, AA+AB=DCA, so that the relation itself can be interpreted as an arithmetic sum. Different symbols correspond to different digits. The relation is presented in a column.

The system is organised into two main components: a solution mechanism, which is able to play the game according to a strategy similar to that employed by human beings, and a tutoring component, aimed at guiding students to learn the mathematical knowledge and reasoning underlying the solution of the game.

The solution mechanism

The mechanism integrates procedural and declarative reasoning, which alternate in a non deterministic way, depending on the situation at hand. The first one, called "domain oriented", is based on the idea of modelling the relation through a set of facts and rules. Facts represent the constraints on the relation and rules represent the arithmetical knowledge which allows reasoning on symbols pertaining to the same column and on the mutual relation between columns. Each rule models an arithmetic skill, as a composition of subskills. Rules are applied to single columns. The second kind of reasoning, called "general problem solving", is used to hypothesize a correspondence between symbols and digits and to verify, by substituting digits to symbols in the given relation, if arithmetical equality is satisfied. This "attempt" strategy is employed when no rule can be applied to the situation at hand. The solution mechanism constitutes the domain knowledge and skill of the tutoring component.

The tutoring component

In order to allow students to follow different learning paths, the tutoring component is subdivided into two modules, called respectively SIMULATOR and GUIDE. As regards the educational aspects, the modules share the teaching goal and differ with respect to teaching strategy. In both cases, the main teaching goal is that of making students learning arithmetic rules and their use in solving a given problem. As regards teaching strategy, SIMULATOR makes students learn through the eyes of an expert who solves problems by giving detailed explanations of the solution process. GUIDE aims at helping students learn by leaving them to solve problems on their own and giving advice on the action to be taken.

As regards the interface, the modules share the external representation of the problem and of the results, but they differ as to the external representation of the solution process and the dialogue with the user. At every moment during the solution process, the student is shown: the initial and the current relation; the sets of admissible values for the symbols. The initial and current relations are presented in a column, and the carriers are explicitly indicated. The solution process is displayed in a window at the bottom of the screen (see Figures 1 and Figure 2). Figure 1 refers to the application of the concept of the double of a number regarding the unit column of the relation DA+ECA=EDB in the SIMULATOR module; Figure 2 refers to the same situation in the GUIDE module.
In the following sections we shall briefly describe the behaviour of both modules; in particular, we will focus on the features they are endowed with in order to help students learn rules.

Simulator

As stated, SIMULATOR furnishes examples of solution processes, together with a step by step explanation. The student chooses the relation to be handled by the system; he may interrupt the solution process at every moment, ask for further explanation, explore freely the rules at disposal or end the process, but he does not take an active part in the solution. The student is supposed to learn rules and their use through the description of how the system uses them. Generally speaking, the use of an arithmetical concept to determine the values (or sets of values) associated with the symbols of a relation (i.e. the application of a rule to a column) can be viewed as the combination of a double-level reasoning: 1) a general observation, referring to some arithmetical concept which can be employed to reason on the column; 2) a particularisation of that observation, regarding the application of the concept to the situation at hand (i.e. taking into account the limitation of the values which can be substituted for symbols). Explanations given by SIMULATOR whenever a rule is applied are organised accordingly.

An example is shown at the bottom window of Figure 1. The column to which the rule is applied is displayed in the form of equation. The description of the rule is organised into two parts: the first one refers to the concept involved; the second refers to the use of the concept within the context. Finally, the resulting admissible values for symbols are indicated, and the current state is modified according to the reasoning followed.

Guide

GUIDE cooperates with a student who has to solve a problem. The student chooses which relation to deal with; he indicates the operation to be performed (i.e. an attempt or the application of a rule), and its parameters (a symbol and a corresponding value in case of attempt, a column and a rule in case of application of a rule). The system intervenes in the process by: 1) preventing the student from performing an attempt when a rule can be applied; 2) giving hints to the student in choosing a rule correctly, whenever a rule can be applied.

The student is supposed to learn rules through their use. The system guides the student in such use on the principle that the capability of using arithmetic concepts for solving symbolic problems (i.e. using rules), is a two-step process: at first, we have to recognise the general arithmetic rule which model the situation at hand; secondly, we have compare the solution deriving from the model with the constraints of the context, in order to discard the results which do not fit the situation. At the age in question, the above process can be better acquired by figuring out possible consequences of a given situation on the basis of some intuitive reasoning and trying to confirm, by examples, the validity of such consequences; repeated experiments of the use of a concept lead to its formalisation.

We, accordingly, based the tutoring activity on examples. Examples are numerical sums which represent applications of a rule to the situation at hand. Examples can refer to correct or incorrect applications. To this end, several examples are shown for each rule. In particular, the tutor shows a series of one-column relations, constituting examples of admissible and non-admissible deductions from the column. Each non-admissible deduction represents an arithmetic misconception or it is a generalisation of the column.

The pupil is required to choose one or more relations. The pupil's answer is used to update the system's hypotheses with reference to the level of learning of the concepts involved in the reasoning. In turn, these hypotheses guide the choice of the analogies and counter-examples presented in the following steps of the dialogue (see Figure 2).

Concluding remarks

In our opinion, computer based educational tools can effectively be employed in didactic practice if they: focus on a central topic; make pupils work on relevant problems; allow results which, from a pedagogical point of view, are rather difficult to obtain without using the computer.

Thus, the system we propose focuses on arithmetic: the game it is based on regards sums of two addenda in the domain of natural numbers. Moreover, the problems handled by the system must be

Sets	Definition Intersection Bijective correspondence
Ordering	Ordering relation Partial ordering Total ordering
Natural numbers	Positional notation Basis of representation Even and odd numbers
Arithmetic operations	Neuter element Carrier Computation
Equations	Solution of simple equations General solution Constraints on the solution
Mathematical reasoning	Hypothesis Deductive reasoning Proof

Table 1: Topics involved in the game

solved using concepts which are fundamental in the primary school curriculum: for example, a relation of the type A+B=A is solved by observing that the sum has a neuter element, and this neuter element is 0. Thus, by assigning to B the value 0 and to A whatever value of the set {1,2,3,4,5,6,7,8,9}, the given relation represents an arithmetic sum. Table 1 shows the arithmetic topics on which pupils are made to work within our system.

Finally, the kind of activity we propose cannot be carried out without help by the computer: it must be noted, in fact, that the solving of a problem of a symbolic nature requires the explicit modelling of the problem as a set of assertions; the solution process is a sequence of transformations from the initial assertions to the solution. Transformations are obtained by applying symbolic rules. The set of rules is established at the beginning and depends on the topic at hand. This process, even at an informal level, is too long and tedious to be carried out by hand; the computer keeps track of the transformations and assures us that the set of data and rules is stated once and for all, thus constituting a strong help in analysing the solution process.

References

Al- Kaudurie, O., & Morgan, S. (1989). The PCMATH system: empirical investigations. *Artificial Intelligence in education*. 1(1), 103-120.

Beishuizen, J., & Felix, E. (1991). Adaptive tutoring of arithmetic skills. *Instructional Models in Computer Based Learning Environments.*, Dijkstra S., Krammer H. P. M. and van Merrienboer J.J.G. (Eds.), Springer-Verlag, 243-261.

Burton, R.R. (1982). An investigation of computer coaching for informal learning activities. *Intelligent Tutoring Systems*, Sleeman D., Brown J.S. (Eds.). Academic Press, Inc., 79-98.

Forcheri, P., & Molfino, M.T. (1991). Designing a knowledge based learning environment for arithmetic concepts, *Computers and Education*, 16,(2), 143-151.

Forcheri, P., & Molfino, M.T. (1989). The Teller Simulator: an automatic problem solver for educational use, *Lecture Notes in Computer Science 360*, Maurer, H. (Ed.), Springer-Verlag, Berlin, 117-131.

Forcheri, P., & Molfino, M.T. (1994). Knowledge based educational system for teaching/learning mathematics, (to appear).

Goldstein, I.P. (1982). The genetic graph: a representation for the evolution of procedural knowledge. *Intelligent Tutoring Systems*, Sleeman, D., Brown, J.S. (Eds.). Academic Press, Inc., 51-77.

Nicolson, R.I. (1992). Design and evaluation of the SUMIT intelligent tutoring assistant for arithmetic. *Computer assisted learning.* Tomek, I. (Ed.) Lecture Notes in Computer Science 602. Springer-Verlag, 491-502.

Nwana, H.J. ed. (1993). The evaluation of an intelligent tutoring system. *Intelligent Tutoring Media*, 1(3), 117-132.

Wenger, E. (1987). Artificial Intelligence and Tutoring Systems. *Computational and Cognitive Approaches to the Communication of Knowledge.* Morgan Kafmann Publishers Inc.

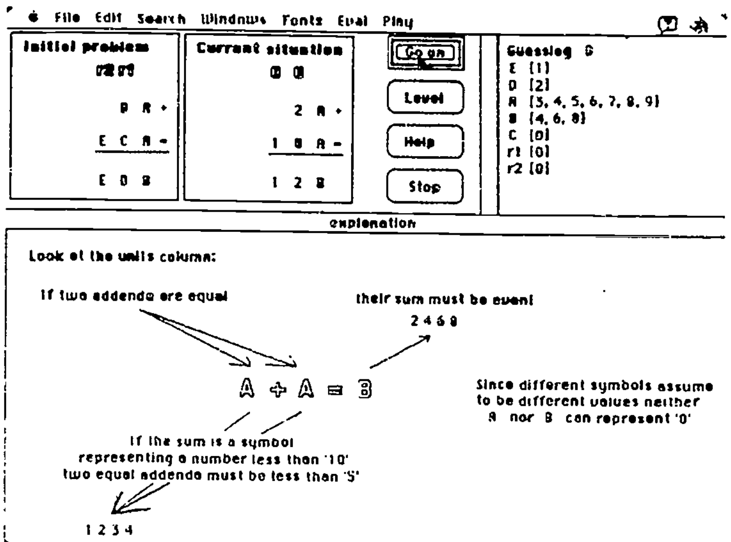

Figure 1. Simulator. A portion of the solution process.

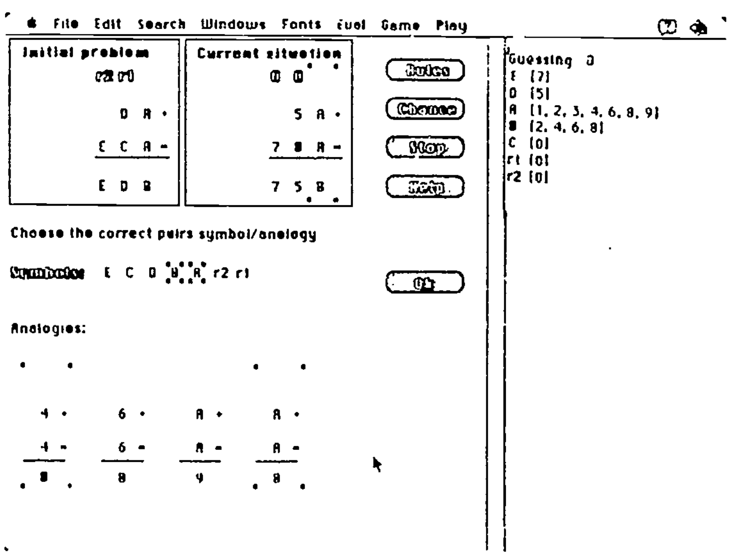

Figure 2. Guide. A portion of the solution process.

Cognitive Constraints on Graph Interpretation Determine the Success of Graphical Software

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Abstract: College students in an atmospheric sciences course studied atmospheric stability and related graphs of temperature and altitude either in a lecture and discussion format or in a interactive software environment. The software presented problem solving tasks using experts' graphs of the interaction of several variables influencing stability. Students in the computer lab made more errors in reasoning about atmospheric stability and its causes than students in the discussion section. Follow-up experiments outside of the classroom (Gattis & Holyoak, 1994) demonstrate that several factors constrain graph interpretation, and that the graphs used in the course violated some of these rules for graph construction and interpretation. Three factors that influence graph interpretation are identified: the fact that by definition slope equals the rate of change of the variable on the y axis, causal relations, and pictorial consistency with visuospatial relations in the world.

Graphs are more than just a device by which national newspapers cope with low literacy levels. Their ubiquity in popular media, however, is one sign that a graph can be easier to comprehend than even the most basic sentence. A variety of studies demonstrate that many graphing tasks can be performed earlier in life and more easily than decoding many other representations. Developmental studies with four to nine-year-old children show that even the youngest group can extrapolate a line to estimate a predicted value (Bryant & Somerville, 1986; Somerville & Bryant, 1985). Perceptual and psychophysical experiments with graphs demonstrate that meaning can be extracted from graphs more quickly and accurately than from other types of displays. Legge, Gu, and Luebker (1989) compared adult subjects' efficiency at extracting information from numerical tables, scatterplots, and luminance-coded displays. Subjects were most efficient at detecting means and variances in scatterplots and least efficient at detecting that information in numerical tables. Legge et al. (1989) concluded that graphs are superior to tables for representing quantitative information because they utilize parallel, spatial cognitive processes. More generally, the ease with which children and adults detect trends in data displayed in graphs is due to correspondences between graphing conventions and hard-wired pattern recognition processes. Graphs represent conceptual information, but employ hard-wired perceptual constraints to do so with minimal processing demands (Kosslyn, 1989; Pinker, 1990; Wainer, 1992).

Cognitive Constraints Simplify Graph Interpretation

Identifying Concepts and Causes

Regardless of whether they are used in a classroom or a scientific laboratory, the purpose of most graphs is to communicate high-level conceptual information and to support reasoning about the relations between two or more variables. Despite the fact that concepts and causes organize mental representation (or perhaps because of that fact), the difficulty of developing and articulating conceptual knowledge and especially causal relations is well documented in developmental and cognitive studies.

Graphs and diagrams are a unique representational form created by a mapping of perceptual and conceptual information. By utilizing hard-wired perceptual abilities, particularly processes for dealing with spatial relations and visual patterns, graphs provide a representational medium in which it is possible to present both concrete and abstract information. The concrete representation of an abstract relation allows graphs to play a fundamental role in representing conceptual knowledge for reasoning and communication. Values, variables, and relations lie along a continuum of abstraction. A value is concrete, a variable is an abstracted common dimension across several values, and a relation is an abstracted common dimension across two or more variables. The graphed relation is a conceptual mapping that often represents a cause and effect relationship between variables. To ensure shared interpretation of

the causal relations represented in a graph, some conventions for mapping perceptual relations to conceptual relations are necessary. Some of these mappings are closely matched to the physical representation (i.e. more area denotes greater quantity; Pinker, 1990) and are rarely violated in graph construction. Others, however, require some training or experience to comprehend. In addition, some of the mappings are more implicit than others. Graph interpretation requires only an implicit understanding of the mappings, but graph construction frequently requires an explicit understanding, especially when two or more constraints on mapping conflict.

Reducing Cognitive Load

The difficulty of graphing concepts and tasks is also a consequence of the complexity of the mapping process required to establish correspondences between the perceptual input and a meaningful mental model. Mapping is the process by which two cognitive structures are placed into systematic correspondence on the basis of parallels between the relations in each. The number of elements that must be represented and manipulated in relation to one another at one time, often called cognitive load, is constrained by cognitive processing limitations. Halford (1993) and many other theorists estimate that humans can process no more than four elements at once.

Graph interpretation involves three tasks of increasing complexity and cognitive load: extracting data, detecting trends, and comparing trends and groupings (Wainer, 1992). Even the lowest level task, extracting data, requires identifying for a particular point the value(s) on one or more axes. This task requires identification and coordination of at least two pieces of information. As the number of variables, number of relations, or level of the interpretation task increases, the load increases. Halford (1993) explains that people manage to cope with tasks that appear to require attention to more than four factors by combining or chunking elements. Graphs are designed to overcome limitations on cognitive processing by building chunked representations: values compose variables which compose relations, and the information in a graph can be considered at one level while ignoring other levels.

The evidence for the ease of graphing contrasts sharply with educational studies reporting that graph comprehension is a particularly troublesome task for students (Clement, 1989; Leinhardt, Zaslavsky, & Stein, 1990). Clement observed that students tended to view a graph as a picture and to confuse slope and height (1989). Leinhardt et al. (1990) reviewed many educational studies documenting students' misconceptions, including iconic confusion, difficulty recognizing functions, and difficulties with abstracting from the graph. Collectively these and other studies indicate that the natural design of graphical representation does not make graph interpretation effortless.

Poor Graph Construction Causes Poor Graph Interpretation

While graphs comprehension invokes built-in perceptual processes, it is not itself not hard-wired. Tversky and Schiano (1989) and Schiano and Tversky (1992) found evidence that the rules used for encoding graphs are not simply properties of the visual system, but rather result from interpreting a figure as a graph. They demonstrated that the label given to a diagrammatic representation invokes a particular set of rules or biases for encoding. Calling the representation a "graph" created a particular perceptual bias (the interpretation of a line orientation was biased toward 45 degrees), whereas calling it a "map" or a "figure" either did not create any bias or biased the interpretation away from all orienting angles (including 45 degrees). These results indicate that graphs constitute a symbol system that is associated with a specialized set of rules connecting the perceptual to the conceptual.

The two previous sources of difficulty in graphs are intrinsic to the tasks of graph interpretation and reasoning with graphs, and graphs have been developed to help the user overcome these obstacles. The final source of difficulty is perhaps the most frequent and yet also the most unnecessary. Most difficulties with graphing interpretation result from graphs that do not conform to cognitive and perceptual constraints (Wainer, 1992). Graph designers are often either unaware of essential graphing conventions or underestimate their importance in allowing a reader to correctly interpret a graph. Many books have been written to mitigate unwitting graphical violations (Bertin, 1983; Tufte, 1990), but graphs are constructed not by designers but by domain specialists who simply wish to convey some finding or develop a tool for data analysis. Experts in a domain often become accustomed to a graph that violates graphing conventions and are able to reason rapidly even with a less than optimal representation. This development is a testimonial the powerful effects of expertise, both with a concept and a representation, but blinds specialists in a field to cognitive limitations on the flexibility of our representational abilities. One example of this problem is presented in the following assessment of a software program developed by atmospheric scientists for use in teaching the concept of stability to college students.

The Sounding Software Lab

Atmospheric stability is the force that influences the move...ent of air and thereby creates weather patterns (Ahrens, 1988). Stability is governed by the relationship between air temperature, altitude, and moisture. The temperature difference between an air parcel and the surrounding air determines its movement. Specifically, a parcel that is warmer than the surrounding air will rise until the two temperatures are equal. This relationship is complex because the temperature of the rising air parcel is also changing: as warm air rises, it expands and cools. A third variable, moisture, influences the rate of cooling because moist air cools more quickly than dry air. Differences in moisture can cause two parcels with the same temperature difference from the environment to have different stability levels. This interaction of three variables makes stability a fairly complex concept for students to grasp. The difficulty of three-variable interactions has been well documented as a frequent source of trouble for science education, in part due to information processing constraints (Halford, 1993). Graphical displays can assist students in overcoming these limitations by providing a visual representation of an interaction. Providing a perceptually chunked representation of an interaction utilizes parallel spatial processes to reduce cognitive load.

The sounding software lab emphasizes a graphical representation of stability and asks students to use data presented in sounding graphs in several problem solving tasks. Atmospheric scientists collect data on temperature and moisture of a particular slice of air, or air parcel, from a balloon as it moves through the atmosphere. The resulting data provides a profile of an air parcel and is called a sounding graph (see Figure 1). The sounding software lab presents several data sets displayed as sounding graphs. Students use the sounding graphs and their data for several tasks, such as calculating the lapse rate (the rate of cooling for an air parcel), and comparing the lapse rates of a parcel and the surrounding air to assess its stability.

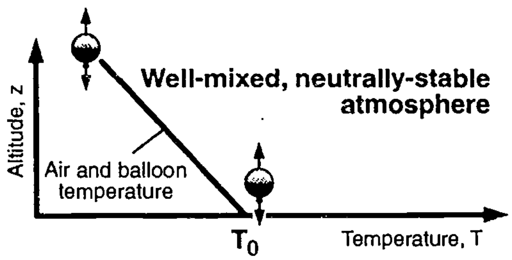

Figure 1. A typical sounding graph used in atmospheric science.

Assessment

The effectiveness of the sounding software was tested with respect to developing a deep understanding of stability in students taking an introductory-level atmospheric sciences course. Because this class fulfills a general education requirement for non-science majors only, the vast majority of the students were non-science majors. 158 students participated in an in-class assessment composed of four classes. Two of the classes participated in the lecture and discussion format and two used the sounding software. Two teaching assistants each taught one control (lecture and discussion) and one experimental (sounding software) class. The control and experimental groups were similar in content, differing only in the source and extent of their exposure to sounding graphs.

Assessment consisted of 13 items. A variety of question types assessed varying levels of conceptual understanding. Several open-ended questions asked for basic definitions and rules for identification of a stable atmosphere, lapse rates, and fronts as well as deeper knowledge about the processes and forces involved in stability. Multiple choice and mapping tasks all focused on causal relations.

Results

On 3 of the 13 items, the control group answered more accurately than the lab group ($p < .05$). There were no significant differences between the groups on the other 10 items.

When asked to explain how to calculate the lapse rate of an air parcel, the control group gave a complete and accurate answer significantly more often. Answers to the open-ended questions were categorized as true, true but not sufficient, and false. Only true answers were scored as correct. A correct answer to the question about lapse rate could include either a propositional description of the change in temperature with respect to the change in altitude or an equivalent mathematical formula. The most frequent true but not sufficient answer given consisted of the lapse

rates for saturated and dry air parcels. Reporting the lapse rates amounts only to recall of one outcome of the procedure, not an explanation of the procedure (which contains important clues to the causal structure of stability). Students in the experimental group gave true but not sufficient answers, or else false answers, significantly more often than students in the control group.

The control group also gave correct answers more frequently than the experimental group on two of the cause and effect matching questions. Both of these questions required identification of causes of stability.

Discussion

Contrary to expectation, students in the computer lab made more errors in reasoning about atmospheric stability and its causes than did students who received a more traditional lecture presentation. All three significant differences favored the control group. Students in the computer lab were not significantly poorer at performing the task of identifying a parcel as stable or unstable (which can be done by memorizing prior examples or lapse rates), but they showed an impoverished understanding of the underlying causal relationship. The present study tested the hypothesis that sounding graphs emphasize the underlying relationship of air moisture, temperature and altitude in determining stability, and would therefore yield a deeper understanding of the concept. The results indicate that this was not the case.

It was hypothesized that the observed deficiencies in the computer lab arose because the graphs used in the software violated cognitive constraints on graph interpretation. Follow-up experiments outside of the classroom (Gattis & Holyoak, 1994) have demonstrated that several factors constrain graph interpretation, and that the graphs used in the software violated some of these rules for graph construction and interpretation. Atmospheric science textbooks and teachers invariably plot altitude on the *y* axis, because this preserves the low-level, pictorial correspondence between *up* in the world and *up* in the graph. The resulting graph of the functional dependency between altitude (the causal variable) and temperature (the effect) violates cognitive constraints derived from the perceptual-to-conceptual mapping between the slope of a line and the rate of change in the effect (dependent variable). Specifically, if the independent variable (IV) is mapped to the *x* axis, and the dependent variable (DV) to the *y* axis, then rate of change in DV with respect to IV maps to rate of change in *y* with respect to *x* (i.e., the slope of the line). This assignment, a graphing convention that we term the Slope-Mapping Constraint, ensures that judgments about rates can be based on the visually transparent mapping *steeper = faster*. However, the standard pictorial-based assignment of altitude (IV) to the vertical axis in sounding graphs violates the Slope Mapping Constraint (since rate of change in the DV will equal the reciprocal of the slope, instead of the slope).

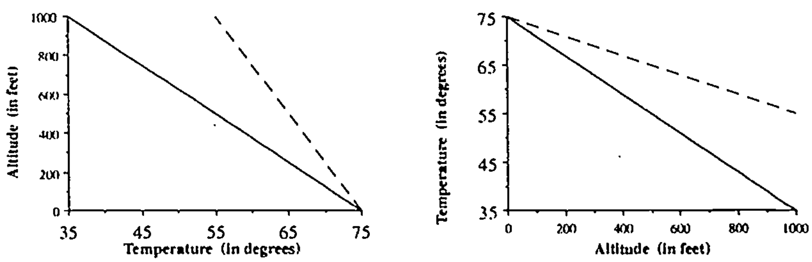

Figure 2. Graphs that violate (Panel A) or conform with (Panel B) the Slope-Mapping Constraint.

Gattis & Holyoak (1994) manipulated factors influencing axes assignment in several experiments using a simplified version of the sounding graphs and the instructional task used in the atmospheric sciences software. We varied the assignments of variables to axes, the perceived cause-effect relation between the variables, and the causal status of the variable being queried. Subjects were given graphs representing the functional dependency between atmospheric altitude and air temperature, along with a brief explanation of the relationship. The graphs either represented altitude on the *x* axis, in accordance with the graphing convention of mapping the IV to the *x* axis that follows from the Slope-Mapping Constraint (Figure 2B), or on the *y* axis in accordance with the atmospheric-science tradition of preserving verticality, but in violation of the Slope-Mapping Constraint (Figure 2A). In the first experiment, only the description of a parcel profile, in which altitude loosely causes temperature, was given to subjects. A second experiment manipulated the causal direction between altitude and temperature by giving half of the subjects the parcel profile description and half of the subjects a cover story describing the movement of a hot air balloon. In the latter story atmospheric air temperature (relative to a constant balloon air temperature) causes altitude (of the balloon). We also varied axes assignment in non-causal conditions in which no cover story was used. In a third experiment subjects were asked to reason about a change in cause as a function of a change in effect, as well as

the opposite case, to test whether people are especially sensitive to violations of graphing conventions in the context of judging the rate at which a cause changes with its effect. All three experiments consistently found that accuracy was greater when the Slope-Mapping Constraint was honored, in that the variable being queried is assigned to the vertical axis. This constraint dominated when it conflicted with others, such as preserving the low-level mapping of altitude onto the vertical axis.

Graph interpretation is constrained by perceptual processes and natural mappings between perceptual relations and conceptual meaning, such as the analogical mapping "steeper equals faster". Even though graph interpretation is an implicit process utilizing hard-wired perceptual processes, graph construction is not. To ensure accurate and efficient interpretation, designers of graphical software must conform to these cognitive constraints.

References

Ahrens, C.D., (1988). *Meteorology today*. St. Paul: West Publishing Company.

Bertin, J. (1983). *The semiology of graphics*. Madison, WI: University of Wisconsin Press.

Bryant, P.E., & Somerville, S.C., (1986). The spatial demands of graphs. *British Journal of Psychology, 77*, 187-197.

Clement, J. (1989). The concept of variation and misconceptions in cartesian graphing. *Focus on Learning Problems in Mathematics, 11*, 77-87.

Gattis, M., & Holyoak, K.J. (1994). How graphs mediate analog and symbolic representation. To appear in *Proceedings of the 16th Annual Conference of the Cognitive Science Society*.

Halford, G.S. (1993). *Children's understanding: The development of mental models*. Hillsdale, NJ: Lawrence Earlbaum Associates.

Kosslyn, S.M. (1989). Understanding charts and graphs. *Applied Cognitive Psychology, 3*, 185-226.

Leinhardt, G., Zaslavsky, O., & Stein, M.K. (1990). Functions, graphs, and graphing: Tasks, learning, and teaching. *Review of Educational Research. 60*, 1-64.

Pinker, S. (1990). A theory of graph comprehension. In R. Freedle (Ed.), *Artificial intelligence and the future of testing* (pp. 73-126). Hillsdale, NJ: Lawrence Earlbaum Associates.

Schiano, D.J., & Tversky, B. (1992). Structure and strategy in encoding simplified graphs. Memory and Cognition, 20 (1), 12-20.

Somerville, S.C., & Bryant, P.E., (1985). Young children's use of spatial coordinates. *Child Development, 56*, 604-613.

Tufte, E.R. (1990). *Envisioning information*. Cheshire, CT: Graphics Press.

Tversky, B., & Schiano, D.J. (1989). Perceptual and cognitive factors in distortions in memory for graphs and maps. Journal of Experimental Psychology: General, 118, 387-398.

Wainer, H. (1992). Understanding graphs and tables. *Educational Researcher, 21*, 14-23.

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Elements of a theory of Algebra for Interactive Learning Environments.

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Abstract: We propose a theory of algebra for Intelligent Learning Environments (ILE) in particular in the APLUSIX project for the polynomial factorization domain. The goal of this theory is to model the resolution process through transformations of expressions and to establish some strategic results.
Our theory include cognitive aspects in order to analyse a student's resolution and to present a student with a solution. Our theory has also formal and computational aspects to establish properties and to facilitate the implementation. These aspects are coming from the rewriting rules domain.

1. Introduction

In this paper, we consider problems that are solved by applying transformations to algebraic expressions. Examples of such problems given to high school students are *factor* $(7x+2)^2-(5x+2)(7x+2)$ and *solve* $(7x+2)^2-(5x+2)(7x+2)=0$.

We particularly focus on the strategic knowledge that students are building up through the resolution process. For reaching a solution, students have to apply transformations and to generate new expressions that form a search tree. The strategic knowledge is guiding the development of that search tree by choosing at each step an expression and the transformation to apply on.

When students are working in a paper-pencil context, the use of strategic knowledge is limited because students need too much time to correct wrong calculations or to calculate branches of the search tree leading to dead ends. Interactive Learning Environments (ILEs) can avoid wrong calculations and allow an easier development of all necessary branches of the search tree. Consequently, it is possible to give to students problems with a more strategic content than usually given in class.

For high school students, the first domain having some strategic interest is the factorization domain. This domain has two characteristics. Firstly, few strategic considerations are usually explicitly given to students who have to build up their own strategic knowledge through factorization problem solvings (Tonnelle 91). Secondly, usual algebraic concepts are not relevant for all contexts from a strategic point of view: for example, the transformations $36x^2-9 \rightarrow (6x-3)(6x+3)$ and $36-9 \rightarrow (6-3)(6+3)$ are usually considered both as factorizations although they do not have the same strategic interest (the last one does not even include the indeterminate x). The transformation $5(x+2)-6(x-1) \rightarrow -x+16$ is usually considered as a development (because it involves distributivity) although its strategic interest is not low (as the usual interest of developments in factorization problems) but good (as the usual interest of reductions) because the involved expressions have a degree equal to 1.

The APLUSIX project (Nicaud and al. 93) is well adapted to the learning of strategic knowledge. It aims at designing ILEs in the domain of algebra for high school students and encompasses systems developed for teaching polynomial factorization. These systems were experimented with high school students. To factorize polynomial expressions with APLUSIX, students have to develop a search tree using *transformations* (e.g.,

$25x^2$-9 $\rightarrow$ (5x-3)(5x+3)) coming from *rewriting rules* (e.g., A^2-B^2 $\rightarrow$ (A+B)(A-B)). They have to choose an expression node, a sub-expression of this expression and the rule they want to apply. Calculations are made by the system which generates the sound transformation and the new expression node. Problems given to students with the APLUSIX systems have a more strategic content than usually in class. For instance, the factorization of $(7x+2)^2$-(5x+2)(7x+2)+2($13x^2$-6) cannot be obtained by factoring out 7x+2 from $(7x+2)^2$-(5x+2)(7x+2), which leads to 2x(7x+2)+2($13x^2$-6) and then to the dead end $40x^2$+4x-12 (the involved students do not know the discriminant). A strategic reasoning can lead to the development of -(5x+2)(7x+2)+2($13x^2$-6) in the first expression, then to $(7x+2)^2$-$(3x+4)^2$ and finally to the solution (4x-2)(10x+6).

When using ILEs for teaching, it is important to develop a theorical framework for the domain. In this paper, we present such a theory including strategic considerations in the framework of the APLUSIX project and the factorization domain.

2. The theoretical framework

Firstly, our theory refers to mathematics providing for example with the definition of polynomials. But mathematics do not emphasise expressions, they only focus on mathematical objects that expressions are representing. Consequently mathematics lack in cognitive aspects. Secondly, our theory includes *cognitive aspects* (Anderson 83, Wenger 87) to make our results well adapted for the student dialogue (helps, explanations, solutions). Finally, our theory includes *formal and computational aspects* (Dershowitz et al. 90) to establish properties and to facilitate implementation.

2.1. Expressions

We distinguish between expressions (e.g., $(x-1)^2$) and the mathematical objects they represent (e.g., the polynomial X^2-2X+1). We note $\mathbb{K}$ any countable set of numbers including the set of integers. Each number of $\mathbb{K}$ is assumed to have a particular single representation called its canonical form. $\mathbb{K}_c$ denotes the set of canonical forms of $\mathbb{K}$. We call *expression* any term built with canonical forms of $\mathbb{K}_c$, the constants x and k (respectively called indeterminate and parameter), the variadic (i.e., having any number of arguments) symbols "+" and "*", the unary symbol "-" and the binary power symbol noted "↑". The second argument of the power symbol is a canonical form of a positive integer. We note x^2 for x↑2 and x-2 for x+(-2). This expressions set is called $\mathcal{T}_{EXP}$. In our framework, $(x-4)^2$ and x^2-8x+16 are two different expressions.

2.2. Semic features and definition of transformation classes

We define *semic features* as mappings from the set $\mathcal{T}_{EXP}$ of expressions to sets called domains. Semic features denote cognitive characteristics of expressions. They allow the definition of transformation classes having a strategic interest. Below are some examples.

The *formal degree* $\underline{\underline{\bar{\text{deg}}}}$ has some analogy with the polynomial degree but is not the same concept. Formal degrees are defined on expressions, not on polynomials. For example: $\underline{\underline{\bar{\text{deg}}}}(2x^3-2x^3+7x)=3$, although the polynomial degree of the polynomial 7X associated to $2x^3$-$2x^3$+7x is only 1. The formal degree allows the discrimination of relevant transformations at a strategic level. For example, it explicits the difference of strategic interests between the transformations $36x^2$-9 $\rightarrow$ (6x-3)(6x+3) and 36-9 $\rightarrow$ (6-3)(6+3): the latter is not interesting because it involves expressions having a null formal degree.

The formal degree allows the definition of an interesting transformation class: the *collapsing transformations*. They are transformations u $\rightarrow$ v such that $\bar{\text{deg}}(u)>\bar{\text{deg}}(v)$, e.g., (5x-2)(x+3)-$5x^2$ $\rightarrow$ 13x-6.

Another semic feature, the *factorization degree* $\underline{\underline{\overset{*}{\text{deg}}}}$, is, in a sense, the number of factors having a formal degree different from 0. For example, the factorization degree of x(x^3-9)(x+1)(x-1) is 4 because the four arguments have a non-null formal degree; the factorization degree of 5(x^3-9)(9+1)(x-1) is 2 and corresponds to the two factors

x^3-9 and x-1. The factorization degrees of the sums x^2+6x-6 and 5+2 are respectively 1 and 0. The factorization degree allows the definition of factorizations *with a strong significance.*

A *factorization with a strong significance* is a transformation $u \rightarrow v$ such that u is a sum, $\underline{\underline{\overline{\mathrm{deg}}}}(u)=\underline{\underline{\overline{\mathrm{deg}}}}(v)\neq 0$ and $\overset{*}{\underline{\underline{\mathrm{deg}}}}(u)<\overset{*}{\underline{\underline{\mathrm{deg}}}}(v)$. For instance, $50(x-1)^2-18 \rightarrow 2(5x-8)(5x-2)$ is such a factorization because $\underline{\underline{\overline{\mathrm{deg}}}}(u)=\underline{\underline{\overline{\mathrm{deg}}}}(v)=2$, $\overset{*}{\underline{\underline{\mathrm{deg}}}}(u)=1$ and $\overset{*}{\underline{\underline{\mathrm{deg}}}}(v)=2$.

The next semic feature involves multisets. Unlike sets, multisets may contain several occurrences of the same element. Consequently the multisets {1,1,2} et {1,2,2} are different. We note >> the usual ordering on multisets of natural numbers. For instance {1,2,3,4}>>{1,2,2,2,4} because after discarding all the common occurrences of elements in both multisets, we obtain respectively {3} and {2,2}, and because 3 is greater than 2.

The next semic feature, the *additive multiset of formal degrees* $\underline{\underline{m}}_s$, is, for a sum or an opposite of a sum, the multiset of the formal degrees of the sum arguments. For example: $\underline{\underline{m}}_s(5x+6x^2-18x(x+1)))=\{1,2,2\}$ because the arguments' degrees are 1, 2 and 2. In the other cases, the additive multiset only contains the formal degree of the expression, e.g., $\underline{\underline{m}}_s(5x(6x^2-18))=\{3\}$. Additive multisets are involved in the definition of *additive groupings.*

An *additive grouping* is a transformation $u \rightarrow v$ such that $\overline{\mathrm{deg}}(u)=\overline{\mathrm{deg}}(v)\neq 0$ and $\underline{\underline{m}}_s(u)>>\underline{\underline{m}}_s(v)$. For instance, $10x^2-6x+4x^2-2x+10 \rightarrow 14x^2-8x+10$ and $15x(x+1)-6x(x+1) \rightarrow 9x(x+1)$ are additive groupings because we have respectively {2,1,2,1,0}>>{2,1,0} and {2,2}>>{2}. A *réduction with a strong significance* is either an additive grouping or a collapsing transformation.

Semic features are required in the definition of *constraint rewriting rules* such as $\overline{\mathrm{deg}}(A)\neq 0 \vee \overline{\mathrm{deg}}(B)\neq 0 \Rightarrow A^2-B^2 \rightarrow (A+B)(A-B)$ allowing the generation of only relevant transformations. For example, the above rule is applicable to the transformation $(6x)^2-3^2$, and not to 6^2-3^2.

2.3. Models involved in algebra

We explicits now different models involved in algebra.

The *formal model* $\mathbf{FM_P}$ includes all the different terms required in algebra: expressions (e.g., $3x^2+8x-2$), semic features (e.g., $\overset{*}{\mathrm{deg}}(5(x-1)(x+3))$) and semantic constraints (e.g., $\overline{\mathrm{deg}}(x^2-1)\neq 0$).

A particular *semantic model* $\mathbf{SM_P}$ and a morphism E defined from $\mathbf{FM_P}$ to $\mathbf{SM_P}$ allow the evaluation of formal terms except expressions. For example, $E(\overset{*}{\mathrm{deg}}(5(x-1)(x+3)) = \overset{*}{\underline{\underline{\mathrm{deg}}}}(5(x-1)(x+3)) = 2$, $E(m_s(x^2+1)) = \underline{\underline{m}}_s(x^2+1) = \{2, 0\}$ and $E(\overline{\mathrm{deg}}(x^2-1)\neq 0) = (\underline{\underline{\overline{\mathrm{deg}}}}(x^2-1)\neq 0) =$ True.

Partial models include mathematical objects only associated to expressions. They define sound transformations. We propose the polynomial model, the function model and the number model where for instance the expression x^2-1 is respectively associated to the polynomial X^2-1, the function $x \rightarrow x^2-1$ and the number 99 if a substitution mapping x to 10 is chosen.

2.4. Concepts in expressions

A concept in expressions (Nicaud et al. 93) is a particular set of expressions involved in the solving process. Characteristics of concepts are called *features.*

For example, Tonnelle (79) established that the students recognize the applicability of the rule $A^2-B^2 \rightarrow (A-B)(A+B)$ to $50x^2-x(5x+3)-18$ by means of clues arising from the square forms $50x^2$ and 18 with a coefficient 2. We define the *square* concept around the two features *square-root* and *coefficient.* The expressions $50x^2$ and -18 belong to this concept because $50x^2$ is the square of 5x with a coefficient 2 and because -18 is the square of 3 with a coefficient -2. As the two coefficient values are opposite, the rule can be applied and $50x^2-x(5x+3)-18$ can be rewritten to $2(5x+3)(5x-3)-x(5x+3)$.

Another concept is the *factor* concept whose features are *expression* and *degree*. These two features are multi-valued, i.e., they may have several values. For example, in $(2x-4)^2(x+7)-x(5x+2)+(x-2)(5x+7)$, the sub-expressions $(2x-4)^2(x+7)$ and $(x-2)(5x+7)$ belong to this concept. The expression x-2 is a common factor of both expressions with the corresponding degree 1. This concept is useful for expliciting common factors and for rewriting $(2x-4)^2(x+7)-x(5x+2)+(x-2)(5x+7)$ to $(x-2)[2(2x-4)(x+7)+(5x+7)]-x(5x+2)$.

2.5. The RM modelling of resolution

The expression t_1 rewrites to t_2 by means of the transformation $u_1 \to u_2$ iff u_1 is a sub-term of t_1 at an occurrence p and t_2 is obtained from t_1 by replacing u_1 by u_2 at this occurrence. For example, $x+x^2*0$ rewrites to $x+0$ with the transformation $x^2*0 \to 0$. The expression t_1 rewrites to t_2 by means of the rule $U_1 \to U_2$ iff t_1 rewrites to t_2 by means of a transformation generated from the rule. For example, $x+10x[(3x)^2-2^2]$ rewrites to $x+10x[(3x+2)(3x-2)]$ with the rule $\bar{deg}(A)>0 \vee \bar{deg}(B)>0 \Rightarrow A^2-B^2 \to (A-B)(A+B)$ because this rule generates the transformation $(3x)^2-2^2 \to (3x+2)(3x-2)$. We use the same symbol as for transformation and write $x+10x[(3x)^2-2^2] \to x+10x[(3x+2)(3x-2)]$.

Experienced students often use mental calculations. For example, they apply the rule $A^2-B^2 \to (A+B)(A-B)$ to $90x^2-40$ in the expression $x+90x^2-40$ and obtain directly $x+10(3x+2)(3x-2)$ using presentation conventions. Such a rewriting is impossible in a syntactical way because 40 cannot be matched with the square B^2. We define the **RM** model allowing such a rewriting.

The **RM** model first includes the equivalence relation ≡ as the transitive, reflexive, symmetric and monotonic by context closure of the binary relation R, defined on $\mathcal{T}_{EXP}$ by u R v iff:

- u is equal to v, up to associativity and commutativity of addition and multiplication; or
- u and v are numerical, u is a power and E(u)=E(v) (e.g., 7^2 R 49); or
- u and v are numerical, u is a product and E(u)=E(v) (e.g., 5*(7+2) R 45); or
- $u=(a^n)^m$ and $v=a^p$ with E(n*m)=E(p) (e.g., $(x^5)^2$ R x^{10}); or
- $u=a^n a^m$ and $v=a^p$ with E(n+m)=E(p) (e.g., x^5x^2 R x^7); or
- $u=a^n b^n$ and $v=(ab)^n$ (e.g., $[x(5x+8)]^3$ R $x^3(5x+8)^3$); or
- u=ca+cb, $\bar{deg}(c)=0$ and v=c(a+b) (e.g., $3(x^2+1)$ R $3x^2+3*1$); or
- u=1v ; or
- $u=v^1$; or
- u=-w and v=(-1)w.

The inference mode of the **RM** model is *rewriting modulo an equivalence relation.* The expresssion s_1 rewrites *modulo* ≡ to s_2 iff there exist two expressions t_1 and t_2 and a rewrite rule R such that: $s_1 \equiv t_1 \to t_2 \equiv s_2$. For example the rule R: $\bar{deg}(A)>0 \vee \bar{deg}(B)>0 \Rightarrow A^2-B^2 \to (A-B)(A+B)$ can be applied to $x+x(90x^2-40)$ in this way: $x+x(90x^2-40) \equiv x+10x[(3x)^2-2^2] \to x+10x[(3x+2)(3x-2)] \equiv x+10x(3x+2)(3x-2)$.

Concepts of expressions associated to rewriting rules are used to find a relevant and equivalent expression. In our example, the concept of square includes the two expressions $90x^2$ and -40 whose square-roots are respectively 3x and 2 and whose coefficients are 10 and -10. The square concept allows the direct deduction of the expression $x+10x[(3x)^2-2^2]$ equivalent to $x+x(90x^2-40)$ and which can be rewriten with the rule R.

*The **RM** model includes transformations, constraint rewriting rules, concepts of expressions, the equivalence relation ≡ in the set $\mathcal{T}_{EXP}$ of expressions and the inference mode of rewriting modulo the equivalence relation ≡.*

Production rules can be used for implementing the RM model. For example, in the systems of the APLUSIX project (Nicaud and al. 93), the application modulo ≡ of the rule: $(\bar{deg}(C)=0) \wedge (\bar{deg}(A)>0 \vee \bar{deg}(B)>0) \Rightarrow CA^2-CB^2 \to C(A-B)(A+B)$ is implemented by the production rule:

85

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if    E is a sum and U is an argument of E and V is an argument of E
  and U belongs-to square with A as square-root  and C as coefficient
  and V belongs-to square with B as square-root  and -C as coefficient
  and [ deg(A)>0    or    deg(B)>0 ]
then  replace U + V in E by C(A+B)(A-B)
```

2.6. A strategic principle

Using theorems of the rewriting rules theory (Dershowitz 90), we proved that the factorization in a strong significance, additive grouping in a strong significance, collapsing transformation and rule set is terminating over the set $\mathcal{T}_{EXP}$ of expressions. This means that there exists no infinite rewriting sequence $t_1 \rightarrow t_2 \rightarrow \ldots$ with such transformations or rules for any expression t_1.

As we observe that the solution paths of factorization problems include a very high rate of factorizations and reductions, the above termination result leads to the following strategic principle **SP**:

To solve a factorization problem, use mainly factorizations and reductions with a strong significance.

Applying the SP principle leads to the development of a finite search tree with a high probability of reaching the solution. On the contrary if developments are used, the potential search tree is infinite because factorizations and developments are inverse transformations and therefore loops may appear.

The APLUSIX solver includes heuristics defined in harmony with the **SP** principle (Nicaud and al. 93). These heuristics facilitate the efficient exploration of the finite search tree obtained according to the **SP** principle. They take into account the *context* such as: *do not factorize an expression if the only expression left is a constant.* They can involve some calculus steps such as: *prefer a factorization generating a factor which is already a factor of another term* (e.g., in x^2-4+(x-2)(x+6)+x(x+6) the factorization of x^2-4 in (x-2)(x+2) generates the factor x-2 which is already a factor of (x-2)(x+6)).

3. Conclusion

In this paper, we have described a theory of algebra for ILEs having cognitive, formal and computational aspects. This theory includes semic features and concepts of expressions, formal and semantic models involved in algebra. Factorizations, reductions and developments with a strong significance are defined using semic features. The **RM** model includes the inference mode of rewriting modulo an equivalence relation. The termination of factorizations and reductions with a strong significance allows the justification of a strategic principle **SP** giving priority to factorizations and reductions.

This theory provides a theoritical framework for the APLUSIX systems. We think that this theory can help to address some major issues in ITS such as the modelisation of the student, the generation of relevant exercises, the management of explanations or helps and the determination of relevant pedagogic interactions.

4. Bibiliography

Anderson J. R. (1983) : *The Architecture of Cognition*, Harward University Press.

Dershowitz N. Jouannaud J.P. (1990): *Rewrite systems*. Handbook of Theoretical Computer Science, Vol B, Chap 15.North-Holland.

Nicaud J.F., Gélis J.M., Saïdi M. (1993) : *A Framework for Learning Polynomial Factoring with new Technologies*. International Conference on Computer in Education 93, Taïwan.

Tonnelle J. (1991): *Le monde clos de la factorisation*. DEA report. Marseille University. France.

Wenger (1987): *Artificial Intelligence and Tutoring Systems*. Morgan Kaufman Publishers.

The Emerging Coalition of Automated Mathematics and Science Education Databases (CAMSED)

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Abstract: A discussion of the Eisenhower National Clearinghouse's Coalition of Automated Mathematics and Science Education Databases (CAMSED). Paper focuses on the long-term vision which is for a user of CAMSED resources to gain seamless access to all the databases maintained by the Coalition and institute parallel searches for items with a single query. Progress to date and various technical and non-technical issues that are being addressed. Tools for conducting research on the Internet both present and future are presented as examples.

The information superhighway is nothing more than slick pavement. More important to travelers on this highway will be the types of vehicles traveling on that highway. The Coalition of Automated Mathematics and Science Education Databases (CAMSED) is like a high speed monorail with special tours and stops for the mathematics and science education communities. Imagine a tour along the information highway where you have one ticket (a free ticket) which includes stops at the world's largest education related bibliographic database (ERIC) as well as the first comprehensive multimedia mathematics and science education database for educators K-12 (Eisenhower National Clearinghouse), and the vast resources of NASA and the U.S. Department of Energy. Want to know where you can get your ticket? Who is the travel agent?

The Travel Agent

Booking your ticket for this journey will be the Eisenhower National Clearinghouse for Mathematics and Science Education (ENC). ENC is funded by the U.S. Department of Education and is located at The Ohio State University. Included in the broad scope and mission of ENC is the effort to continually improve science and mathematics education in the United States. To do this, our nation's teachers need better access to the best instructional materials and programs. ENC's vision for this effort is to provide a central source through which teachers can locate the instructional materials for teaching science and mathematics. ENC's participation in CAMSED has two components. First, ENC will create and maintain a comprehensive multimedia collection of materials and programs. Second, ENC will deliver access to this collection using both traditional and advanced computing and telecommunications technologies.

What is in the ENC Collection?

The Clearinghouse will collect and create the most up-to-date and comprehensive listing of mathematics and science curriculum materials in the nation. The list or catalog of materials, the text of some of the materials, and evaluations of them will be made available in a database in a variety of formats, including print, CD-ROM, and electronically online. From ENC you will be able to receive an easy-to-use catalog of mathematics and science curriculum materials, including materials available in print, video, audio, software, other graphics, and CD-ROM. For each item, there will be an abstract of the material in the catalog and information about availability.

How can I access the ENC Collection?

ENC provides free information about mathematics and science curriculum materials. If you have a computer, a modem, or access to the Internet, and a printer, many of the materials that the Clearinghouse collects will be available free online. So far, this seems like a traditional database available on the Internet. What is unique about the ENC collection is that you are not going to be limited to the resources of one clearinghouse. The focus of the ENC effort is to combine the existing Internet resources so that teachers can have a starting point that will guide them to the information that they most desire. Access to the Clearinghouse and Coalition collections will be facilitated through a Macintosh, Windows, and VT-100 connection. There will be a client-server architecture designed to respond to user actions.

Many schools do not have the technology available right now to use the online technologies. For those users, ENC will produce mini-catalogs and information about the Clearinghouse collection in print. As schools acquire the technology, the Clearinghouse will make extensive information available about using the catalog and using the online system. In addition, the Clearinghouse is establishing regional demonstration sites to provide help to users through workshops and walk-in assistance.

The Transit Authority

So, who decides what travels along this information highway and what traffic rules will apply? The Coalition will be a voluntary organization of information providers, with member groups working collaboratively to fashion standards, protocols, and operating policies. The goal is to establish interoperability among an array of database providers who maintain or are developing electronic resources useful to science and mathematics teachers. By forming a federated database, CAMSED will provide users the benefit of single-point access to scattered resources without having to create redundant collections of materials or physically consolidating resources. From a single point of access, users will be able to construct a search of linked databases with a single search strategy.

Since the Eisenhower National Clearinghouse has the major responsibility for making instructional materials accessible to mathematics and science teachers in the nation, the Clearinghouse will take the lead in bringing the Coalition together and facilitating agreements on standards and operating procedures. It is the intent, however, to leave all database building activities in the hands of those who have created existing resources or are developing new resources. In this way, resources will be developed by groups having special expertise, interests, or resources, but access to the electronic resources will become a shared and mutually beneficial endeavor that makes the greatest possible use of emerging information technologies and practices.

Along with standards and protocols regarding the ways in which databases are linked and accessed, there will be standards relating to the search vocabulary, the core components of database records, and the means of linking similar fields across disparate databases and database types. Given the diverse resources that will be linked, developing standards that apply to text as well as non-text resources will be a major challenge to interoperability and the development of a unified search procedure. In addition to searching a variety of databases with one search procedure, it is intended that users will be able to seek additional related materials once a particularly useful resources has been located. That is, if an initial search leads to a database record of particular interest, there will be a mechanism for finding items within the federation of databases that are strongly related. This is similar to the relevance feedback information provided by WAIS.

A High Speed Monorail

Though still in the early planning stages, CAMSED is viewed as a major step forward toward consolidating electronic resources and providing a federated database of resource materials for mathematics and science educators. This evolving Coalition will include the resources of various federal agencies and other educational organizations that have developed and maintain continuously updated electronic databases. Coalition members will likely include the ERIC system, NASA, the U.S. Department of Energy, Scholastic, and others. The long term vision is for a user of CAMSED resources to gain seamless access to all the databases maintained by the Coalition and institute parallel searches for items with a single query. Where possible, the resources

obtained from a search will be available to the user in as many forms as possible. Some formats might include full-text of the item, scanned images of pages, video clips, or still images of slides.

The Nuts and Bolts Fastening the Rails

The ENC collection of databases can serve as a model for databases in the Coalition. The primary resource of the clearinghouse is a bibliographic database. This database is deployed on a Unix-based platform with a search engine. Several other databases contain information to supplement the core bibliographic database. Some of these databases include (a) standard text in machine readable form, (b) image data, (c) evaluation data from online submitted evaluations, and (d) other multimedia data types.

The databases will be accessed by the end user through a state-of-the-art client server architecture which allows individual users to utilize their existing personal computing systems to access the Coalition resources in a highly interactive fashion. The clients are being developed by ENC to have built-in support for multimedia data types. Fully functional clients will be available on the Macintosh and Windows platforms. Access to the text-based information will be made available to VT-100 clients. To make the client as dependable as possible, ENC will be using national and international standards for delivery of data. Standards include Transmission Control Protocol/Internet Protocol (TCP/IP) and Z39.50. Z39.50 is a protocol which is commonly used synonymously with Wide Area Information Servers (WAIS). While not entirely accurate, the two terms are merging to combine their functionality. Essentially, using the Z39.50 protocol, the barrier for accessing information in multiple databases with one search query is eliminated. However, Z39.50 is not an interface, nor is WAIS. They are tools which are used to find information contained in databases. The databases can be located on the same machine/server, or they can be located thousands of miles apart. There exists many tools for retrieving information on the Internet. Each have been developed because of a need for finding information. This same basic need for access propels our monorail on the information highway.

On a Parallel Track

As part of the National Information Infrastructure (NII), the U.S. Federal government is proposing a Government Information Locator Service (GILS) to help the public locate and access information. GILS would identify public information resources throughout the Federal Government, describe the information available in those resources, and provide assistance in obtaining the information. As currently planned, GILS would use the network technology and the American National Standards Institute Z39.50 standard for information search and retrieval so that information can be retrieved in a variety of ways, and so that GILS direct users can ultimately gain access to many other major Federal and non-Federal information resources. GILS would also include automated linkages that facilitate electronic delivery of off-the-shelf information products, as well as guide users to data systems that support analysis and synthesis of information. GILS is designed to be a cooperative effort with the Information Infrastructure Task Force (IITF).

For CAMSED, the GILS effort is significant. Current efforts are attempting to link the GILS record with the CAMSED intelligence. Imagine this scenario, a user of the CAMSED resources enters a search query. The query is analyzed and compared with the GILS records to find appropriate resources to institute parallel searches across. A user might enter a query for star-clusters. The server would look through the known information about resources belonging to the Coalition and run the search against databases containing information about stars but not against those that don't.

Road Maps... Internet Discovery Tools

> The Internet was born about 20 years ago, out of an effort to connect together a U.S. Defense Department network called ARPAnet and various other radio and satellite networks. The ARPAnet was an experimental network designed to support military research—in particular, research about how to build networks that could withstand partial outages (like bomb attacks) and still function...It was designed to require the minimum of information from the computer clients. To send a message on the network, a computer simply had to put its data in an envelope, called an Internet Protocol [IP] packet, and "address" the packets correctly. (Krol, 1994, p. 13)

Basically, all that the Internet does is facilitate the moving of 1's and 0's from one place to another. To send these bits of information, the Internet has a two part process that is typically spoken in the same breath... TCP/IP. To understand TCP/IP, it can be broken down as IP is the addressing portion with a small amount of data attached to it. TCP is the process for sending lots of packets and check for errors in the process. Granted, this is a very over-simplified view of TCP/IP. TCP/IP is what happens underneath the surface. Applications like electronic mail, remote login, and file transfer use the low-level routines of TCP/IP to make sure that the data it is sending has integrity. If you read a book on how the Internet routes information with bit streams and so forth, you will be ready to pull off on the information super highway road side rest!

Telnet, FTP, Mail, and News

There are four basic categories of applications available to Internet users. Certainly, these are not the only types of applications but usually found on most sites. *Telnet* is one method for logging into other computers on the Internet. The computer you connect to may be located on your campus or halfway around the world. *FTP* stands for File Transfer Protocol. FTP is the command set that allows two sites to transfer files. Many people are familiar with anonymous ftp which simply means that logins are not required to access information on a site. *Electronic Mail* is what many people associate with the Internet itself. Electronic mail lets users on the Internet send and receive messages to or from other users on the Internet. *USENET News* is like a community bulletin board where users on the network can read messages and post public messages for others to view. To put it simply, USENET News is the world's largest bulletin board service. These basic applications are command driven. Many users who think that the Internet is "hard" have the picture of the ftp commands in their mind that they will have to learn before they can use the Internet.

As is often the case, the mother of invention is necessity. To remove the need for remembering all of the Internet commands, another layer of software is used on top of the basic applications. These tools are considered more user friendly. When users are exposed to the applications that allow them to use the basic applications without remembering the commands, the typical response is... "Oh, that's all there is to it?"

Internet Gopher

The Internet Gopher is a navigating tool that takes the features of the Internet and puts them all into one handy little application. Things such as ftp and telnet are combined. Gopher allows users of the Internet to *burrow* around from site to site without knowing the IP address or domain name of a machine. The user selects a menu item which presents information to them. Gopher was developed by the University of Minnesota to allow various departments on campus to provide information at different sites on campus and require no training for the users of those sites. The idea quickly grew into an Internet navigation tool. Users were able to take the pointers set up by Gopher servers and find vast resources on the Internet. The sites available to users of Gopher are collectively known as *Gopherspace*.

NCSA Mosaic

Mosaic is a client application. The client connects to servers. Servers for information displayed by Mosaic are part of the World Wide Web (WWW). The WWW is a hypermedia system originated by CERN, a high energy physics laboratory in Switzerland. Initially envisioned as a means of easily sharing papers and data between physicists, the Web has evolved to the next generation of Internet navigation tools.

NCSA Mosaic, developed at the National Center for Supercomputing Applications at the University of Illinois at Urbana-Champaign is a network information browser. Mosaic allows you to retrieve text, graphics, sound, and even video clips. Mosaic uses Universal Resource Locators (URLs). The locators combine information from several Internet tools such as ftp, Gopher, WAIS, and others.

ENHANCE

The Eisenhower National Clearinghouse Handy Academic Network Tool (ENCHANT) is a client application being developed at ENC to provide access to the clearinghouse databases and limited Internet resources. ENCHANT is divided into roughly four parts (a) the integration layer, (b) the database tool, (c) the communications tool, and (d) the evaluation tool. The integration layer will handle logins and user verification. The database tool will allow users to search across CAMSED compliant databases. The database tool will conform to Z39.50 version 3 on the back end, but have an easy to use interface for the user. The communications tool will combine the two network applications mail and news. The evaluation tool will be used to allow users to send evaluations of materials back to ENC staff. This is a facility whereby a teacher can try out one of the items cataloged in the resource database and then provide an evaluation so that other teachers can see it before they buy or try an item.

Client applications are being developed for Macintosh, Windows, and VT-100 terminal emulation. The graphical interfaces of the Macintosh and Windows platforms will have full functionality while the terminal emulations will be limited to text based information on screen with download capability where appropriate. ENHANCE users will be able to use the connectivity they have to access resources. If the machine has an Ethernet connection to the Internet it will be used. A bank of modems and a toll-free 800 number will be available for SLIP-type (limited form of SLIP) connection for non-networked schools and home users.

Travelers on the CAMSED Highway

CAMSED users will be educators at all levels who are seeking resources to support instruction in science or mathematics. The resources may include instructional plans, media, datasets, images, or background information. If the highway and transportation system are well constructed, a user will only have to find one door into the system and put together one search strategy, or itinerary, to seek out needed information. The infrastructure will be nearly invisible, and several databases will be searchable simultaneously using natural language. To the extent possible, the system itself will be multi-lingual, allowing users to interact with the system in their preferred language. The system will also accommodate a variety of computer platforms and resource formats so that users need not be particularly concerned about using the "right" hardware, software, or command procedures. In short, CAMSED is intending to provide an electronic transportation system for accessing widely scattered resources for science and mathematics students, teachers, and parents without requiring special equipment, technical skills, specialized vocabularies, or complicated procedures.

References

Krol, E. (1994). *The whole internet: User's guide & catalog*. Sebastopol, CA: O'Reilly & Associates.

Linear Algebra in Mathcad: An Interactive Text

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Abstract: Mathcad in the Windows environment is used to support a discovery based learning format for linear algebra. The course is taught as a laboratory with no formal lectures. Students actively participate in the mathematics to develop a concept, connect it to preceding ideas, experiment with its properties, and use it with applications. This format emphasizes reading, collaborative learning, writing, and connection of topics. Goals include the improvement of both long range retention of the subject matter and problem solving skills.

Background

'In recent years, demand for linear algebra training has risen in client disciplines such as engineering, computer science, operations research, economics and statistics. At the same time, hardware and software improvements in computer science have raised the power of linear algebra to solve problems that are orders of magnitude greater than dreamed possible a few decades ago. Yet it appears that in many courses, the importance of linear algebra in applied fields is not communicated to students and the influence of the computer is not felt in the classroom, in the selection of topics covered or in the mode of presentation. Furthermore, a worthwhile but sometimes overemphasis on abstraction may overwhelm beginning students to the point where they leave the course with little understanding or mastery of the basic concepts they will actually use in their careers.'

We believe that student use of computers ... can reinforce concepts from lectures, contribute to the discovery of new concepts and make feasible the solution of realistic applied problems (Carlson, Johnson, Lay, & Porter, 1993).

The Report of the Linear Algebra Curriculum Study Group (Carlson, et. al.) has come at a time of great national interest in the improvement of mathematics education at all levels. At the collegiate level two documents from the National Research Council have played a central role. *Everybody Counts: A Report to the Nation on the Future of Mathematics Education*, reviewed the way we teach mathematics and outlined a plan for action while *Moving Beyond Myths*, presents an action plan for revitalizing undergraduate mathematics. Common to these documents is wide agreement that the traditional lecture approach to teaching mathematics is not working. Students are not achieving mastery of the subject matter and retention of the material that is learned rarely lasts beyond the final exam. This is particularly distressing in linear algebra with the increased demands from client disciplines who use computational tools that depend on linear algebra. It is widely known that mathematics is not a passive activity and that lasting knowledge comes from active involvement with ideas on a variety of levels. An active approach in which students learn by doing provides more opportunities for mastery and retention. Implicit in this change is the empowerment of the student to control his or her learning environment.

Lynn Steen describes this phenomenon clearly. *'Learning takes place when students construct their own representation of knowledge. Facts and formulas will not become part of deep intuition if they are only committed to memory. They must be explored, used, revised, tested, modified, and finally accepted through a process of active investigation, argument and participation. Science (and mathematics) instruction that does not provide these types of activities rarely achieves its objectives.'* (Steen, 1991)

The ever increasing power of desktop computers and software provide the opportunity to change mathematics instruction from a teacher centered lecture approach to a learner centered interactive environment. One form of change is an interactive text as described by Brown, Porta, and Uhl (1990). *'Imagine a mathematics text in which each example is infinitely many examples because each example can be redone immediately by the student with new numbers and functions. Imagine a symbolic or numerical computer routine into which fully word-processed descriptions can be inserted at will between lines of active code. Imagine a text that has better graphics and plots than any available in any standard mathematics book and imagine that the amount of graphics is limited only by the computer memory instead of the cost and weight of printed pages. Imagine that ... all three-dimensional graphics are perfectly shaded and can easily be viewed from any desired viewpoint. Imagine a text in which a student can launch his or her own graphic and calculational explorations with graphics and calculations appearing as the student desires.'*

Such an approach was pioneered by Uhl, Porta, and Davis at the University of Illinois with their Calculus and Mathematica series (1994). Our initiative focuses on linear algebra and has a similar vision for a student oriented learning environment supported by technology.

Goals and Instructional Tools

The broad goals of our interactive text project are student understanding and mastery of major linear algebra concepts, recognition of the interplay between concepts, retention of the fundamental principles and capabilities of the subject, experience with individual or small group projects, emphasis on responsibility for learning, and the development of problem solving skills.

Many of these goals are consistent with those of a traditional lecture based linear algebra course. However, with an interactive text format the tools available for shaping the learning environment are more varied and offer more flexibility. The primary tools for a standard course are the text materials, verbal delivery to the group (lectures), limited question and discussion sessions, and possibly the response to student homework exercises. With the exception of verbal delivery, we use no formal lectures, all of these tools are available with an interactive text format and so are many others. Naturally the software platform provides expanded instructional opportunities with symbolic and numerical computation capabilities as well as graphics. In addition the textual material can contain instructional formats which include *observe* (something happens in real time), *alter and explore*, *design an experiment to investigate*, *leading questions aimed at discovery*, *guess or conjecture* followed by verify, and *write about it* (explain). The classroom itself supports alternative strategies through collaborative opportunities with peers as well as with the instructor. Much more one-on-one discussion or explanation between student and instructor is common place. In fact, the instructor becomes a daily resource for consultation about mathematical ideas.

In our implementation of interactive text we also set weekly goals for material which are followed by detailed checking of student work. The work not only includes exercises, but also imbedded questions using instructional strategies listed above. Of particular importance are those that require writing about the mathematics and the 'summarize' question that is included in each section. Prompt feedback for this student work is provided on a regular basis. In addition at Temple University the course meets an additional period each week for a discussion of the week's work. The discussion is student oriented, highly participatory, and often reveals connections between concepts through student interaction (and probing by the instructor). Such a forum has been well received by the students and provides an opportunity to connect the current ideas to those to be encountered in the next assignment.

Our Interactive Text

Our interactive text for linear algebra uses the Mathcad computer algebra system in the Windows environment. Mathcad is a commercially available mathematics-engineering computational platform that has a variety of specialized 'handbooks' available for topics in both the high school and the college curriculum. (Our development is the only interactive text implementation of a topic at this time.) We view Mathcad as a smart electronic blackboard; that is, it displays mathematical expressions the way they would appear in a 'standard' mathematics text or as an instructor might write as part of a lecture. Text and graphics can appear on the same screen and the student can respond with text, mathematical expressions, or additional graphics on the screen. In effect the screen becomes a notebook which a student personalizes by their interaction with the topic under study. What started as an instructional tool becomes the student's integrated learning environment. (At the inception of this project the only other similar presentation environment was Mathematica. Now other products are emerging which support the integrated capabilities we have incorporated.)

Mathcad has six important tools that we have used to develop our interactive materials. These software capabilities reflect some of the alternative instructional formats that are used in the our laboratory approach to linear algebra.

1. Mathematical expressions are displayed in mathematical format.

2. Expressions can be evaluated numerically.

3. Expressions can be evaluated symbolically.

4. Graphs can easily be drawn and altered.

5. Text can be presented in document form which is easily extended or modified by a user.

6. Materials generated in other Windows programs can be pasted into our documents.

No previous experience either with Mathcad or Windows is assumed. Mathcad is easy to learn without formal instruction since it is icon based, has built-in help, and a consultant (namely the instructor) is available at all class sessions. We introduce both the Windows environment and Mathcad through hands-on interactive units that involve prerequisite notions from calculus. We also use this opportunity to open a discussion about several basic linear algebra models that will reappear throughout the course. These models reflect the major topics of systems of linear equations, iterative prediction, and eigenvalues and eigenvectors. This introduction of models establishes the theme of an applications oriented course where new mathematical tools provide increased opportunities for understanding the basic nature of problems.

Our basic instructional format is 'discovery based' learning. In this format we design learning tasks, not presentation lectures. The emphasis is on student learning through guided discovery tasks, not teaching in the traditional 'telling' mode. Hence it is important to attempt to use the student's point of view rather than the mathematician's point of view. As such we have incorporated geometric connections to linear algebra to stimulate a visual aspect to topics whenever possible. This dual approach often develops better mental images of mathematical processes than that supplied by purely algebraic manipulation of expressions.

In a discovery based approach our students actively participate in the mathematics to develop a concept, connect it to preceding ideas, experiment with its properties, and use it with applications. In this form we emphasize reading, talking, writing, and the connection of concepts.

> **Reading:** The students must read, interpret, and understand the interactive text. In doing so they participate in its development. Rather than present material in a 'telling fashion' (there are no lectures) we use an informal style of interaction that exposes structural foundations of concepts. Questions are asked without the answers having been presented previously. (This

provides a conceptual form of problem solving.) Students are encouraged to guess, conjecture, relate, and to just 'Try it!'. Formal definitions or theorems appear as a summary of a concept or activity.

Talking: We encourage collaborative learning by asking the students to work in pairs. Since all class work is lab work we want students to talk about the mathematics and bounce ideas off one another. Joint homework (which is really lab work) is encouraged. The instructor responds to questions more with guided return questions than an exposition on the topic. (It takes self restraint to stifle the urge to lecture.) Many questions deal with the writing issues described below. Often a student seeks guidance on formulating a written response.

Writing: Many of our discovery activities require a written response (a sentence or two; a short paragraph) to complement a numeric or symbolic manipulation. Writing promotes clarification to enable communication of thoughts. It is also an opportunity to synthesize current concepts with previous ideas. Every section in our text concludes with an individual exercise to summarize the mathematics learned in their own words. This helps both the student and the instructor, who can point out misconceptions and get a feel for class patterns of comprehension. (We have found that the summary responses get better in mathematical content and overall style as the course progresses.)

Changes

The role of the student has changed from passive receptor as an attendee to a lecture to an active combatant with mathematical ideas, concepts, and articulation of ideas. Thus there is an increased level of participation and responsibility. Students quickly find that they need to develop a steady pace for learning in this active mode. There is an increased time commitment and available of computing resources outside of scheduled class time is a high priority. Such changes may initially cause some students to feel undirected. Thus it is important to establish early on a cooperative climate in the lab.

The role of the instructor has changed from direct presenter, when lecturing, to guide and consultant. The instructor must keep students from getting caught in 'local traps' which can lead them too far astray, but must resist temptations for lecturing when student discovery is close at hand and preferable. Of course there will be times where the instructor must provide more guidance and information to those having extreme difficulties. We have found that the instructor actually expends more effort and devotes more time to discussions with students in this instructional mode.

The topics in our interactive text look very much like those in a traditional linear algebra course in the United States. However, we often introduce concepts in a different order. For instance, dot products in R^n are introduced early in order to easily formulate the matrix multiplication scheme, introduce orthogonality, and discuss projections. The notion of a linear combination is used long before we talk about span and subspace. Iterative concepts are introduced via a Markov model in the first class. We then return to give further development to this important area as new linear algebra is developed. In our interactive mode we have found that the course may not 'cover' as much but will provide a better personal knowledge of concepts for students. We have used more applications than when we have taught in the standard format. Discovery through the guise of an application has an appeal to students and often seems less intimidating.

Assessment of student performance has been done by testing individuals, not learning groups. Hill has used a combination of in-lab exams and individual take-home problems, while Porter uses take-home exams exclusively. No significant advantages or disadvantages to either of these testing styles has been observed so far. The measurement of retention of material for future use is elusive. During the second year of this project some of our first year students are taking other courses that require linear algebra. We currently have little information as to their performance.

Reactions

Student attitudes toward the active learning style have been quite positive. We have results of midterm and end-of-term surveys which are encouraging and helpful. Several excerpts follow.

'The way the course is given is very good because while we are learning math, we don't realize we're learning math, because we're so distracted by the computer. This is very good because it takes the boredom away from the classroom which is almost always there.'

'I was able to take part actively in the learning process rather than just reading some material and then hoping later to decipher its meaning.'

'... this course took a great deal of time.'

'I began to look forward to working on the labs and coming to class.'

From the linear algebra community there has been interest in this approach. We have been contacted by several instructors expressing interest in testing our materials. Several external reviews are in progress. We hope to have several other sites using this material in the near future.

Summary

Our project has completed two years of development. We feel that the text materials are in a stable state that can accommodate a number of types of beginning linear algebra courses. Naturally as we continue to use the materials the contents evolve to accommodate the needs of our students. So what is interactive for the student is true of the text itself. Another user could tailor our materials to their situation.

So far our interactive text has been used with small groups. Students are generally enthusiastic about the active format although the required time for students and the instructor is more than in a standard course. The benefits seem to be worth the extra efforts, and Hill and Porter have learned more about teaching linear algebra than they expected.

References

Brown,D., Porta,H., and Uhl,J.J.(1990). Calculus and Mathematica, *Priming the Calculus Pump: Innovations and Resources.*, MAA Notes #17, p.105-106.

Carlson,D., Johnson,C., Lay,D., and Porter,D.(1993). The Linear Algebra Curriculum Study Group recommendations for a first course in linear algebra. *College Mathematics Journal*, Vol.24, No.1, pp. 41-46.

Everybody Counts: A Report to the Nation on the Future of Mathematics Education(1989). National Research Council.

Moving Beyond Myths(1991). National Research Council.

Steen,L.A.(1991). Reaching for Science Literacy, *Change*, Vol.23, No.4, July/August, p.13.

Uhl,J.J., Porta,H., and Davis, W. (1994). *Calculus & Mathematica*, Addison-Wesley, Reading, MA.

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Technology and Staff Development -- What's The Fit?

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Abstract: Achieving the goals we aspire to for all K-12 students requires, among other things, new roles and practices for teachers. The following conditions are important for teachers to learn to teach in new ways: access to images of learning theories in action, a community of colleagues, a learning community of support, in-classroom support, and both time and mental space. Can technology help create these conditions for teachers? Videotapes, teleconferences, interactive television, and other resources are helping teachers form professional networks and obtain images of change in action, but it is essential that technology be used to help "create the conditions" for teachers to learn rather than as an end unto itself. Two collaborative projects, *Tune in Math and Science* and *Michigan Gateways*, are examples of programs with the potential to help math and science teachers learn to teach in new ways if they are used appropriately by local teachers and administrators.

"Scientific literacy." "Mathematical power." "Higher order thinking skills." Such terms characterize the ambitious goals we aspire to, for all of America's students (NCTM, 1989; MSEB, 1988; AAAS, 1990). Most educators recognize that achieving these ambitious goals for all students requires equally ambitious changes in school organization and management and in home/school/community linkages, as well as in new roles and practices for teachers. Simply "improving" teaching isn't enough, if <u>all</u> children are to achieve what <u>some</u> children currently achieve.

What is required of teachers is truly challenging. Teachers must respond to major transformations not only in what we want students to know and be able to do but also in how we think students learn these things. Although Michigan's teachers are as dedicated and talented as teachers anywhere, for the most part they--like teachers everywhere--have had few opportunities to develop the full range of knowledge and skills required.

Given the magnitude of the changes required, and the urgency of the need for opportunities for professional development, what does technology offer to help teachers learn to teach in new ways? Before we can answer that question, we must understand that transforming one's practice and roles requires considerable new knowledge, understanding, time, and effort. Moreover, many are convinced that certain conditions seem essential for teachers to learn to teach in new ways (McDiarmid, 1994):

- <u>Images of what the new ways of teaching and new roles in school could look like</u>. Information about theories of learning, for example, must be accompanied by examples of the theories in action. While prescriptions are not helpful (even if they were possible), teachers are helped to envision their new strategies by seeing others teaching in ways that illuminate and underscore the new goals and conceptions of learning.

- <u>A community of colleagues, and occasions and opportunities to discuss with them the meaning of these images for their own roles and practice</u>. A community of colleagues working together to make changes in their own teaching provides both encouragement and a safety net for teachers trying out new approaches. Opportunities to work and deliberate together are essential as teachers test ideas

and refine strategies.

- Residence in a larger learning community that includes administrators, students, parents and community members, school boards, and business people. As teaching and learning is transformed, classrooms and schools look less and less like parents and community members remember them. To address the in- and out-of-school learning needs of children, schools and communities must work and learn together.

- Support in the classroom for changing their practice. Good coaching improves the performance of both athletes and teachers--and in both areas the top performers continue to seek out and benefit from other experts' analyses of the performance and assistance in improvement. The classroom is the arena of performance for teachers, and their coaches must be on-site.

- Time and mental space. Changes of the complexity and magnitude that teachers are now called upon to make don't happen overnight. If fact, these changes don't "happen" at all, but rather occur by dint of hard work and over long (multiple year) periods of time. Teachers who are actively engaged in rethinking and redesigning their practice report that a significant obstacle is number of demands on their attention.

Can technology help create these conditions for teachers? Certainly the potential seems there. Images are increasingly provided by videotapes and in periodic teleconferences and occasional television programs--images of "new" teaching that can be replayed and discussed in depth by a school or department faculty. In some places, distant colleagues meet face-to-face via 2-way interactive TV to discuss and debate such images; soon, videophones will make such interactions even more accessible. Moreover, electronic networks are changing our understanding of professional communities: "virtual communities" are forming, both nationally and in Michigan, as teachers discuss problems of practice on computer bulletin boards and electronic "chats". Increasingly, satellite-based interactive teleconferences allow teachers in multiple sites to obtain information, exchange views, and discuss issues in community with other experts. "Partnership" projects--linking schools and communities in collaborative support for student learning--are proliferating, encouraged by the requirements of federal, state and private funders. While in-classroom support for changing practice is harder to imagine via technology, 2-way fiber-optical linkages. or satellite-broadcast programs such as Michigan's *Tune In Mathematics and Science* (described below) suggest some possibilities.

Although technology seems to offer educators a rich venue for professional development, we will not help schools realize the potential of technology unless we keep sharply focussed on "creating the conditions" rather than on "utilizing the technology." Two Michigan-based programs illustrate both the promise of technology-based professional development and its limitations.

Promise and Limitations: Two Michigan Examples

Tune In Math and Science (TIMS) and *Michigan Gateways* [1] are two complementary multi-technology programs designed to help math and science teachers learn to teach in new ways. *Tune In Math and Science (TIMS)* is a program of professional development for teachers organized around courses for middle mathematics and science students. *TIMS* originates from studios at GMI Engineering and Management Institute in Flint and at Michigan State University in East Lansing. In 1993-94 *TIMS* offered five courses for students in grades 6-9: Math I, Math II, Algebra, Science II, and Science III, featuring nationally validated curricula delivered by award-winning teachers and modelling instruction in the spirit of the national reforms. Each course broadcast three free, live, half-hour classes per week, via satellite. In the studio, the broadcast teacher instructs both the students from a local school and students in receiving classrooms--and their teachers; the receiving sites interact via telephone with the on-air class and teacher. The staff development programming includes weekly hour-long staff development broadcasts for each course, as well as quarterly day-long drive-in sessions and a week-long summer institute for teachers.

TIMS provides teachers with images of "this kind of teaching;" receiving teachers can analyze the approaches to teaching that are being modelled and make sense of them through their own students' experience.

Through the interactive staff development broadcasts and through the periodic face-to-face staff development sessions, participating teachers can discuss aspects of their own classrooms, using the broadcast teacher for individual assistance and becoming a part of a growing community of colleagues discussing their own practice. To strengthen local learning communities of colleagues, receiving teachers can organize discussions and analyses of the images of teaching and curriculum that *TIMS* projects--discussions that involve both other program participants and non-participants. Because *TIMS* is carried into some schools via local cable, in these areas teachers can even encourage parents and community members to share in the experience and learn together with them about advancing students' mathematical and scientific literacy.

Consonant with the goals of *TIMS*, *Michigan Gateways* is a 30-minute, magazine-format, news and information program for math and science teachers. Broadcast via satellite and public television approximately monthly throughout the school year (and available free), each *Michigan Gateways* program features a classroom that illustrates an interesting approach to teaching; in-depth exploration of an issue facing mathematics or science teachers in Michigan; reviews of resources that might be useful to teachers who are exploring curriculum, instruction and assessment alternatives; and updates on events of broad interest to teachers. A Guide (available free) is prepared for each program, offering additional resources to help teachers develop local communities of colleagues through activities and discussions based on the program. Electronic bulletin boards sponsored by the program offer teachers opportunities to share discussions with colleagues in other schools.

These two programs--*Tune In Math and Science (TIMS)* and *Michigan Gateways*--suggest some of the possibilities offered by technology. The programs' experiences and external evaluators agree, however, that the effectiveness of the programs as professional development depends on the attitude and determination of local teachers and administrators. The message is clear: technologies provide us with access to images, information, even other learners--but we must focus our efforts on helping to create the collegial conditions teachers need for learning.

[1]*Tune In Math and Science* is a collaborative project of GMI Engineering and Management Institute, Inc, Michigan State University, and the Michigan Partnership for New Education with funding from federal and state agencies, private foundations and not-for-profit organizations, and business and industry. *Michigan Gateways* is offered by Michigan State University in cooperation with the Michigan Partnership for New Education and GMI Engineering and Management Institute; funding for the program is provided by a grant from the Annenberg Foundation/Corporation for Public Broadcasting Elementary and High School Project for Mathematics and Science. For further information on the two programs, contact either of the authors.

References

National Council of Teachers of Mathematics (1989). *Curriculum and evaluation standards for school mathematics.* Reston, Va: NCTM.

Mathematical Sciences Education Board (1989). *Everybody counts.* Washington, DC: National Research Council.

American Association for the Advancement of Science (1990). *Science for all americans.* New York and Oxford: Oxford University Press.

McDiarmid,G.W. (1994). *Realizing new learning for all students: a framework for the professional development of kentucky teachers.* Lexington, KY: The Partnership for Kentucky School Reform. University

Interactive Spreadsheet Templates and Higher Level Problem Solving.

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In 1961, the Education Policies Commission defined the central purpose of American education as "the development of the ability to think" (EPC, 1961). This central purpose has been reaffirmed several times since the original document. While not precluding other goals the EPC made it quite clear that all other goals are, to some extent, dependent upon the accomplishment of this "central purpose."

Elaborating on how this "central purpose" is to be accomplished the EPC indicated that the only techniques that were likely to be successful were those that involved active acquisition of information and utilization of that same information. In essence the active development of the rational powers, recalling and imaging, classifying and generalizing, comparing and evaluating, analyzing and synthesizing, and deducing and inferring, will ultimately produce the thinking individual.

If the EPC set a purpose for education, the field of developmental psychology has given us ways to understand what stimulates learning and how cognitive development takes place. Piaget viewed cognitive development as an incremental process driven by the learner's effort to accommodate new input into their existing cognitive structure. (Phillips, 1969) His model envisioned the learner progressing from thought bound by perceptions and concrete experiences to high level abstract thought.

In an attempt to build a pedagogical model blending both the EPC purpose of education and developmental learning theory, physicist Robert Karplus, later to become dean of the graduate school at the University of California at Berkeley, developed a "learning cycle" approach to teaching science (Karplus, 1978). He applied this approach to his major elementary science curriculum development effort, The Science Curriculum Improvement Study. The learning cycles approach, still in use in science education, has also been applied to a variety of other subjects.

This learning cycle approach involved three phases: exploration, invention, and application (Meyers, 198?). In exploration the learner is introduced to a concept, phenomenon, or system through concrete experiences in which the learner manipulates, probes, questions, and generally exercises his/her natural curiosity. The teacher assumes the role of catalyst or facilitator, subtly moving the learner in the direction of abstractions to be learned later. The teacher's tools are primarily leading and probing questions.

In the invention phase, concepts are developed making use of the learner's experiences from the exploration phase. The teacher serves not as a dispenser of knowledge but rather as a coach assisting the student in accommodation, to use a Piagetian term, or in the constructivist sense, to synthesize understandings within the content of their existing knowledge. Indeed to some extent each learner "reinvents the wheel." The job of the teacher is to ensure that the student's "wheel" is congruent with "wheels" as they are currently understood. This critical phase of the learning cycle is often the most difficult due to the predisposition of many teachers to see that the learner gets the "right answer" as quickly as possible. It is at this phase that the learning cycle approach often breaks down and the teacher returns to a more didactic approach.

Indeed what happens in a large number of cases is that a modified version of invention makes up the entire teaching/learning experience. The pressures to "cover material" result in no time for the exploration phase and the application phase being limited to working a few written problems from the textbook. Applying Bloom's taxonomy (Bloom, 1956) and being rather generous it would appear that the highest level cognitive activity taking place in such a class is comprehension. To develop higher order thinking skills the learner must be involved in activities which present the opportunity to solve real problems using more than a recipe. The application phase of the learning cycle provides such an opportunity.

To initiate the application phase a problem is posed which can be solved through use of the concepts "invented" in the previous phase. In solving the problem the learner, especially those at lower developmental levels, may use a concrete materials centered approach. Through this process of inquiry relationships between concepts can be discovered. Not only does this process reeinforce concepts invented earlier it also involves the application of higher order thinking skills and enhances the learner's abilities to deal with abstract thought.

Just as important is the fact that during this problem solving, as in most problem solving, the unexpected is likely to be encountered. The skilled teacher turns these unexpected experiences into new explorations and the learning cycle has returned to its origin.

Many tools have been and are being employed in the implementation of the learning cycles approach to teaching and learning but perhaps none hold more promise in science and mathematics teaching than spreadsheet software. Let's examine the learning cycle approach as applied to a common science topic, electrical circuits, and see what role spreadsheets might play.

The class of students is first grouped into groups of four and each group is given a flashlight battery and bulb and a 20 cm length of insulated bell wire. The instructions are simply "See what you can do with these items." Battery holders or bulb holders are not used as they make the end result almost obvious.

Most students know that there is a relationship between battery and bulb that produces light but are unaware of the nature of that relationship. At first, the wire seems to be of little consequence and initial efforts involve placing the bulb in contact with the battery in a variety of ways. The fact that the bulb does not light is always a source of frustration.

After numerous unsuccessful attempts to light the bulb the students will finally decide to try to use the wire in some manner. Again they try more unsuccessful combinations of contacts but finally, and usually more by chance than by design, the bulb lights. This always results in great excitement and waving of hands to get the teacher to come see what they have done. Ultimately all groups, either by continuing their random efforts or by getting assistance from other groups, will light the bulbs, and more importantly will be able to repeat the process. They have now discovered a closed circuit.

This closed circuit that has been discovered is concrete. It can be seen and manipulated. But to be of real value, the abstract concept of closed circuits must be invented. At this point the teacher becomes more prominent and through the use of models, drawings, and perhaps film or video, leads learners to the conclusion that for any bulb to light a complete conducting path must exist from one pole of the battery, through the filament of the bulb, and then to the other pole of the battery. The abstract concepts of current, voltage, and resistance must be invented by the teachers and integrated into their concepts of closed circuits. These activities constitute the invention phase of the learning cycle.

Unfortunately, invention is often unsuccessful due to the belief, on the part of the teacher, that the learners simply have to be told the concept. Nothing is farther from the truth. Receiving information can in no way be equated to comprehending and internalizing that information. In fact the invention phase of the learning cycle is usually lengthy and often requires frequent use of concrete materials.

It is important to note that no mathematical relationships have been mentioned to this point. The reason is that in science the mathematical relationships developed are abstract representatives of concrete phenomenon and must be developed slowly by the student. This is when the spreadsheet becomes a valuable tool.

Using today's powerful spreadsheet software, which have integrated graphics capabilities, it is possible to simulate experiences which might not normally be provided in middle or high school and in many cases higher education. Because of lack of equipment, or time, or just a feeling that it really isn't important, in most school experiences the learner rarely has the opportunity to collect, organize, and interpret data. Spreadsheets can counter the lack of equipment by simulating situations, can reduce the time factor with powerful analysis tools, but can do little about the attitude that it's just not important to provide this broad range of experience.

One must remember that using spreadsheet simulations should not supplant actual experiences, when those experiences are possible, but rather supplement and support them. For almost all learners, higher level concepts and abstractions are best formed when associated with some concrete phenomenon within the learners experiential framework. This is the reason that actual manipulation of concrete objects and not simulations are used in the exploration phase of the learning cycle.

Figure 1 is a template developed with Microsoft Excel (Kellogg, 1993). It represents the simplest of series circuits, having one battery, one resistor, and connecting wires. For data collection purposes meters have been placed in the circuit to simulate the measurement of currents, voltages, and resistances. All cells are locked except the cells in which the voltage of the battery can be entered by the learner and the value of the resistor which can also be changed by the learner. As the battery voltage and/or the value of the resistor is changed the appropriate voltage and current will be indicated on the meters.

The groups of students, now at computers, are simply told to "see what you can do with the computer template." Thus begins another exploration. The students' quickly learn, usually by trying to change everything on the template, that only the battery voltage and the value of the resistor can be changed. They also discover that a change in the battery voltage produces change in the current and volt meters while a change in the value of the resistor produces a change in the current meter.

Now is the time for the teacher to provide some structure to the process. The groups are asked to design an experiment to determine if any relationship(s) exists among the variables, voltage, current, and resistance, and to perform the experiment using the spreadsheet template. In order for this part of the activity to be successful the students must have studied and understand design of experiments including identification and control of variables. They should also be accustomed to keeping careful written record of data.

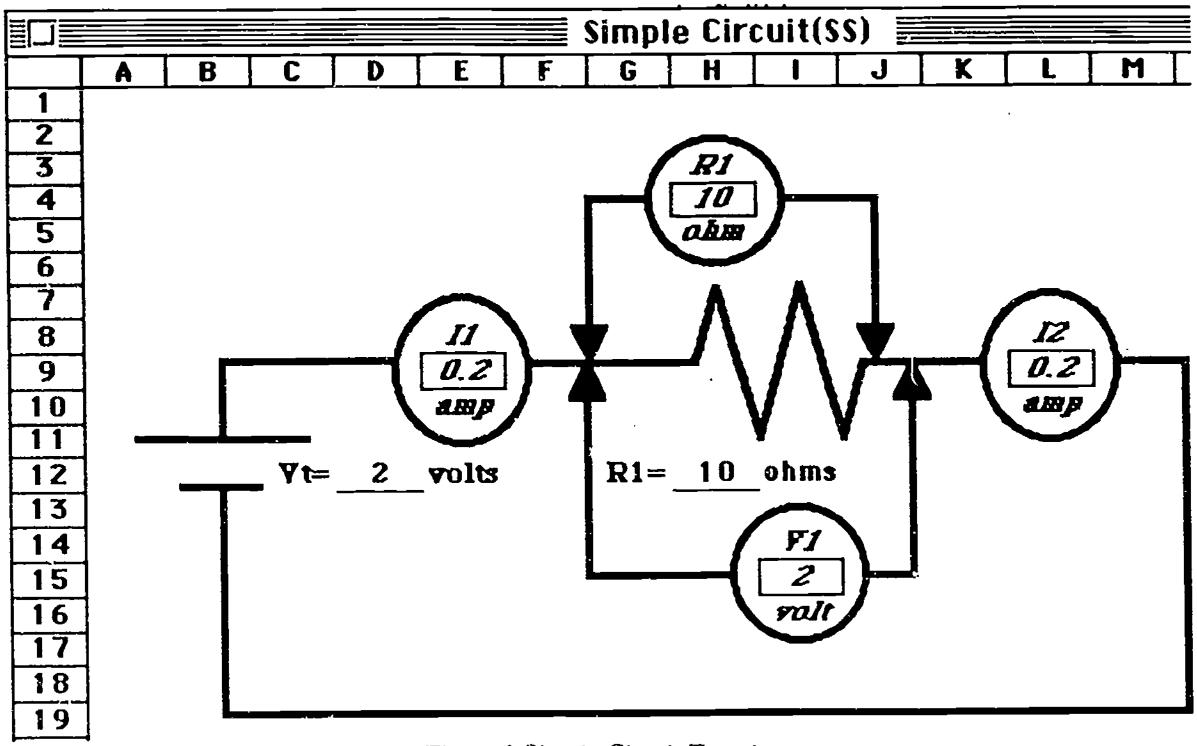

Figure 1 Simple Circuit Template

Once data have been collected the groups are ready to analyze those data and synthesize generalizations about existing relationships. Making the transition from raw data to graphs and then to a generalization about the phenomenon is a process mastered by few students in either K-12 or higher education. Interpreting graphs and developing generalization based on those graphs represents a venture into the highest levels of thinking. At the same time it represents a level of abstraction that can confound the average student unless accompanied by concrete ties to real-world experiences. The design of the experiment and the collection of real or simulated data provides such a tie.

Not only are data obtained from the simulations but the analysis of those data is greatly enhanced through the use of spreadsheets. The laborious process of paper and pencil construction of graphs that most of us experienced in the not-to-distant past is no longer a factor inhibiting meaningful data analysis. Production of high quality and accurate graphs becomes almost automatic when using a spreadsheet.

By using the spreadsheet to graph the data obtained from the simulated experiment the learner will discover a direct relationship between voltage and current and resistance and current. Usually this is not accomplished spontaneously by the learner but rather in conjunction with a good deal of skillful questioning and guiding on the part of the teacher. Learners often have to return to the batteries and bulbs to fully develop their understandings. This blend of concrete manipulatives and simulated experiments combined with the rapid data analysis capabilities provided by the spreadsheets offer the learner a much better opportunity to use higher level thinking skills and to deal with abstractions.

Of course it would have been much faster for the teacher to have told the learner that V=IR, worked a few problems on the board, assigned the odd numbered problem for homework, and left the classroom with a feeling of accomplishment. But this low level approach has been used for years and has failed to produce students who retained, used, or expanded on what they "learned."

The preceding example demonstrates how spreadsheet simulations can play a role in a learning cycle approach which places learners in a situation in which they must collect and analyze data to arrive at some generalization about relationships among variables. The activities are the essence of science and indeed represent solid applications of higher level thinking. The powerful tools of todays spreadsheets and the learning cycles approach to teaching science and mathematics form an efficient partnership for assisting the learner to develop the ability to think.

Bibliography

Bloom, B. (1956). *Taxonomy of educational objectives, handbook 1: Cognitive domain.* New York: David McKay Company Inc.

Educational Policies Commission. (1961). *The central purpose of American education.* Washington, D.C.: NEA.

Furth, H. (1970). *Piaget for teachers.* Englewood, NJ: Prentice-Hall, Inc.

Holt, J. (1982). *How children fail..* New York: Dell.

Kamii, C. (1994). The Six National Goals: A Road to Disappointment. *Phi Delta Kappan*, 75(9), 672-677

Karplus, R., and others. (1968). *Science teaching and the development of reasoning.* Berkeley, CA: Lawrence Hall of Science, University of California.

Kellogg, D. (1993). Spreadsheet circuitry. *The Science Teacher, 60* (8), 21-23.

Lovell, K. (1966). *The growth of basic mathematical and scientific concepts in children.* London: University of London Press Ltd.

McPeck, J. (1981). *Critical thinking and education.* New York: St. Martins Press.

Meyers, C. (1988). *Teaching students to think critically.* San Francisco: Jossey-Bass Publishers.

Phillips, J. (1975). *The origins of intellect: Piaget's theory.* San Francisco: W.H. Freeman & Company.

Sanders, N. (1966). *Classroom questions: What kinds?* New York: Harper and Row.

Compressed Video Networks For Delivering Science and Mathematics Instruction

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Abstract: The potential and current use of compressed video networks to deliver science and mathematics instruction is discussed. This newly affordable technology is being used in several ways in Tennessee. Courses and special programs are being taught using this technology to all ages of people throughout Tennessee. This technology enables fully interactive high quality instruction where instructors and students see each other, hear each other, and can interact in a variety of ways. Unlike satellite programming, where two-way audio is the only interaction possible, with compressed video body language signals are available to the instructor as well as audio. Currently, there are over twenty-five videoconferencing classrooms implemented in Tennessee.

Throughout the US and other countries of the world, educational institutions are beginning to seriously reexamine current instructional techniques and are looking for the most cost-effective means of delivering instruction. Some of the things driving this reexamination are declining student populations, new graduation requirements, changes in the required skills for entering today's workforce, and governmental regulations related to student safety. This reexamination comes at a time when the nation as a whole is 'discovering' telecommunications and the "information highway" is being touted as the revolution of the future. Consequently, schools are taking a hard look at telecommunications technology as a possible restructuring tool.

Previous Constraints

Schools have long been aware of the advantages of using telecommunications solutions for some educational purposes but have considered videoconferencing technology far too expensive for day-to-day use. Additionally, regardless of whether they are higher education institutions or K-12 institutions, most classrooms are without that critical linkage for telecommunications -- a telephone line. Without access to a phone line there can be no telecommunications! A recent quote in the New York Times by Reed E. Hundt, FCC Chair really brings this point home,

> *"There are thousands of buildings in this country with millions of people in them who have no telephones, no cable television, and no reasonable prospect of broadband services. They're called schools."*

Another major constraint inhibiting the implementation of telecommunications solutions has been the cost factor. This factor has been the biggest deterrent to implementing phone lines into classrooms. Regardless of whether you were talking about simply using audioconferencing or electronic mail solutions, telephone access and long distance charges have been major barriers to implementation for cost-conscious schools. The idea of letting instructors and students loose in a room equipped with a phone that is capable of 'dialing' long distance numbers is one that gives school administrators nightmares. In all fairness to these administrators, line item budgets must be considered in setting up such systems. Because of the new demands being put on the telephone service providers for new services, this situation can be handled through a variety of programs offered. These programs enable schools to pay a set fee for a certain amount of usage as opposed to being charged on a per call basis.

The misconception that you have to have fiber optic cabling if you are going to be able to have what everyone really wants — a system that enables instructors to not only see their students but to have full interaction with them regardless of whether they are located in the same room or many miles away has been a constraint in the past. With the new systems and software available now, fully interactive systems are available using the POTS (plain old telephone system) that currently serves the schools. One of the advantages to using the installed copper based network is that regardless of what building you might want to connect to, you can count on being able to do so. An additional advantage to using compressed video on copper is the reduced cost. Even where fiber is available, many schools have chosen to use compressed video on copper due to the high transmission charges assessed for transmission on fiber by their telephone service providers.

An additional constraint is the cost and performance issue related to videoconference equipment. As recently as three years ago, videoconferencing systems that used compressed technology were really unacceptable for use by schools. Jerky movements, the lack of satisfactory lip synching, and the smearing and tiling that existed in compressed video systems resulted in educators saying, "thanks, but no thanks." On top of all these problems, the cost to outfit a typical classroom could run as much as $250,000 — not an amount that was anywhere close to affordable. These problems have virtually disappeared in today's technology enabling schools to take a new look at the use of these systems.

Uses of Compressed Video in Tennessee

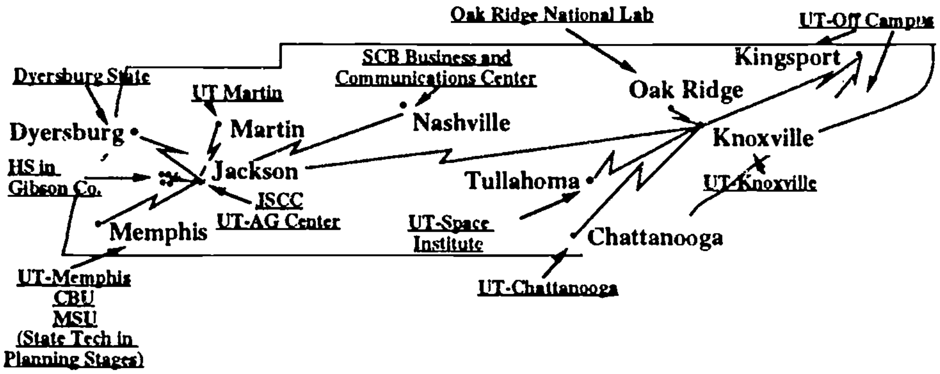
In Tennessee, the use of compressed video for delivering math courses started in the fall of 1990. A pilot project funded by South Central Bell Telephone Company through assistance from the Tennessee Public Service Commission provided five high schools in Gibson County, Tennessee, with videoconferencing equipment. That first year, Calculus was one of three courses taught using the network. The schools had looked at their current class offerings, and determined that Calculus instruction was a major need. Like other rural communities in other states, qualified higher level mathematics instructors were difficult to find. This provided the other schools with a course they had not been able to offer previously.

That same year, 1990, the University of Tennessee at Memphis medical school purchased their own equipment to deliver nursing programs between Memphis and Jackson, a community fifty miles away (see Tennessee Telecommunications Map). In this case, the remote location selected was within the UT Family Practice Clinic in Jackson. The driving force for the implementation of this program was the need for training coupled with the lack of available time for students to travel to Memphis to attend classes. The advantages to this arrangement were numerous — students could do their laboratory work and field experiences in the facility where they were obtaining their training, qualified medical personnel were on site to provide assistance when necessary, and students could quickly see how what they were learning applied in the 'real world.'

Even with the problems of smearing and tiling, these two uses of videoconferencing provided an opportunity for educators throughout Tennessee to see the impact this type of technology could have on the delivery of science and mathematics related subjects. As a result of the lessons learned in these two programs, proposals for implementing videoconferencing systems in educational institutions were developed throughout the state. Many systems were purchased, and point-to-point conferences began to be common between main campuses and off-site locations. In a point-to-point configuration, only two locations can participate in a videoconference. While this can be very satisfactory, the educational institutions in Tennessee wanted access to more than just one other point. Consequently, an additional piece of hardware was required if they were to be able to connect to multiple points — a multi-point control unit (MCU). Fortunately, South Central Bell Telephone Company was interested in installing an MCU as a trial and did so with the cooperation of the educational institutions.

Today, there are over twenty-five compressed video videoconference classrooms in Tennessee tied together by multi-point control units on loan from South Central Bell Telephone Company. Each week, over 50 hours of classroom instruction is delivered using these systems. The types of training varies from continuing education programs to assist currently employed professionals to keep current, to upper division classes leading to doctoral degrees.

The Tennessee Telecommunications Network



The videoconference classrooms have provided these educational institutions the opportunity to deliver high quality fully interactive courses across a wide geographic region to all kinds of people. Some of the advantages of this type of delivery are:

- sophisticated equipment can be used to deliver courses to locations without this sophisticated equipment
  - One professor does a laser show for students located miles away
  - An astronomy professor can do presentations and teach courses to students at remote locations
- experiments now banned by federal regulations can be demonstrated at a remote location providing students the feeling of actually being in the room with the professor
- computer software and interfaces can be used and all students can see what's happening without the need for each student to have their own computer
- students can interact with the professor in real time with the professor watching students and seeing their reactions to instruction
- instructors are able to use a variety of technologies to teach subjects that are difficult to teach in a lecture-only classroom

The videoconference equipment currently being used in all the classrooms in Tennessee includes the following:

- VideoTelecom codec
- 2 Video Cameras
- 4 Monitors (2 in the front of the room and 2 in the back of the room)
- 1 Microphone for each set of two students (most often table microphones)
- 1 Lapel Microphone for the instructor
- 1 Elmo Light Table (serves as an overhead, slide projector, and whiteboard)

The Tennessee Telecommunications Network at this time runs on the regular copper based telephone network at 384 kb. The machines are all capable of running at 768 kb or even 1.5 kb according to the needs of the particular institution. Additionally, when the Tennessee network transitions to a fiber based network, these machines will be able to make the transition without having to be replaced (a key consideration in the selection of hardware).

As the use of the network by medical personnel increases, specialized equipment will need to be purchased to enable full diagnostic capabilities. There are now two medical schools using the network, one in Knoxville, and one in Memphis some 365 miles apart. They have submitted requests for this equipment, and once a source of funding is identified, this equipment will be purchased. Once that purchase is made, not only will they be able to use the network for instruction, but they will also be able to actually train students on diagnostic procedures from remote locations.

The use of the videoconference equipment in Tennessee is growing exponentially not only by educational institutions, but by communities throughout the state who are now installing Network Resource Centers.

These centers are designed to provide access points to the Tennessee Telecommunications Network in all areas of the state. The idea of having to quit your job and move to a particular town to obtain a particular degree will eventually be replaced by being able to stay where you are and simply drive downtown, or a few miles to get a degree.

A recent article in Network Tennessee, states, "... At the University of Tennessee at Martin, they are using 'Reaching out to TEACH Someone' as their masthead for their expanded distance learning program." This really does sum up the way everyone feels about the use of videoconferencing equipment in Tennessee. The participants in outlying regions no longer feel so isolated as they can now develop a real relationship with remote instructors because of the high level of interaction provided by this technology. In the K-12 schools, students have even had romances blossom between students located in other locations on the network.

For more complete information on this technology and what it takes to get started, there are many publications available. The *Telecommunications Technology Planning Manual* produced by South Central Bell Telephone Company of Tennessee has a section on Videoconferencing that details the various options available, explains what each option would include, discusses the capabilities of the various systems, lists what it takes to equip a classroom, and explains anticipated costs. Additionally, the resource section includes references to many other publications with information on equipping videoconferencing classrooms.

References

Hodges, J., & Kellogg, J. (1994). Distance Learning. *Telecommunications Technology Planning Manual*, 37-56.

Kellogg, J. (Fall 1993). Reaching Out to TEACH. *Network Tennessee* 8.

Science, computers and children in the elementary school

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Abstract: In Australia, the use of computers within the home is becoming widespread and the number of computers in elementary schools is steadily increasing. Children are familiar with playing adventure games that often include a component of problem solving. This type of software can become the focus of learning science using a thematic approach. Computer utilities including word processors and databases support children thinking and working scientifically on projects. LEGO TC LOGO enables the exploration of the use of a computer for remote control through the construction of models and associated programming. Software packages in classroom programs foster the development of skills and understandings in interesting and relevant ways. Some strategies being used by teachers to integrate the use of computers within their elementary science programs is discussed in this paper.

Science education programs

In Victoria, science education programs for children have been developed autonomously within the elementary school. Government publications have been prepared periodically to inform curriculum development by teachers. *Science in the Primary School* (1980), emphasised the development of attitudes and skills within defined concept areas. *The Science Curriculum Frameworks* (1988), overlaid a science, technology, society and personal development approach inclusive of local issues and constructivist learning. Currently, *National Science Curriculum Profiles* which define specific learning outcomes are being modified to suit the Victorian situation. The priorities of school communities for the education of children, combined with the autonomy of these communities has led to great diversity among science programs.

Access to computer resources to support science education also varies greatly. Some children have limited opportunities to use a computer because it is shared with another class. More fortunate children have access to computers permanently located within their classrooms as well as having lessons in a dedicated computer room. Each situation has its own challenges for teachers and these require different strategies, for example, teacher demonstration, the use of work contracts and time schedules.

The use of computer software in science education is gradually becoming more common. Software enables the computer to be used in different ways, including the exploration of remote control systems, for the development of problem solving and inquiry skills, or as the focus for integrated curriculum (Fyfe, 1985). Learning is enhanced by the exchange of children's ideas that occurs in cooperative working groups. Examples of some approaches developed by teachers are discussed in the remainder of the paper.

1. A thematic approach

Often the first type of software package used in the classroom is an adventure game. A teacher's interest is captured, and familiarity with the program establishes the necessary confidence to use the computer with children. Imagination and the planning of activities in a range of different curriculum areas can lead to months of thematic work woven around the experiences at the computer (Willing & Girard,1993). Children become very committed and willing to spend time during lunch hour and out of school to complete set tasks.

Dragon World (1986) and *Flowers of Crystal* (1984) are two well used packages related to the popular topics *dinosaurs* and *protecting the environment*. The usual curriculum can easily be abandoned to the excitement of solving the challenges presented. Groups of children work together. Tasks are clarified and experienced by different children in different sessions at the computer. Lots of communication occurs as children record what

happened while using the computer, search out relevant information and discuss what to do next. Classrooms may be transformed into places where children are enjoying actively working together (Fox, 1986).
Science can be taught in a more holistic way using an integrated curriculum approach. For example, when using the program *Flowers of Crystal* (1984) in which protecting the environment is an issue, exploration of the social aspects of science can be included.
Hands-on activities are often avoided in science. Therefore, it is important when planning a thematic unit to clearly indicate appropriate science activities for children to do. Figure 1 shows some examples of activities associated with the software Raft-Away River (1984). Learning outcomes from each different curriculum area also need to be carefully monitored and mapped onto expectations for the particular year level being taught.

<u>Knowledge</u>

Exploring:
- Displacement of water by objects
- Dissolving substances
- Minibeasts living in water
- The effects of water pollution

<u>Technology</u>

- Building bridges and rafts
- Testing different materials for cleaning up oil spills

<u>Society</u>

Investigating:
- how people change rivers and oceans
- the history of boating
- the role of rivers and oceans in the development of settlements

Figure 1. Science activities for Raft-Away River (Fotopoulos, 1994)

A next step would be the selection of a science topic for the focus of a thematic unit. There are an increasing number of software packages with a specific science focus including, *Learn about animals* (1989), *Build a circuit* (1992), *Muppet Labs* (1992) and *A field trip to the rainforest.* (1991). Science is brought out into the open when it is linked to activities in other curriculum areas through use of the software. The excitement generated by the thematic approach becomes associated with science and encourages more practical activities.
Science related software packages offer other advantages. Risk free environments are created in *Build a circuit* (1992) and *Muppet Labs* (1992) where children quickly and easily undertake experiments without the fear of making mistakes. Opportunities to make observations not easily accessible within the classroom are presented to children in *Learn about animals* (1989) and *A trip to the rainforest* (1991). The latter package includes a database to support research and inquiry learning.

2. Using computer utilities to support science learning

Word processing is commonly used in the classroom and can improve presentation of reports from science experiments, enable articles to be included in school newsletters or to make classroom books. A language approach has also been taken to introduce children to the features of databases including *Microsoft Works* (1989), *Claris Works* (1991) and the *Bank Street School Filer* (1986). Big books are used as a source of data, for example, fields can be set up to record observations of Jillian's pigs (Gilman, 1988) encouraging recall of aspects of the story the children have heard and learning about information technology.
Unfortunately the use of databases as a part of science programs is less common. Science activities provide a wealth of opportunities for database use. Hartson (1993), describes student projects where a database is used to record observations of birds during field trips, plant growth experiments in the classroom and rock samples. An inquiry approach to the learning of science is supported by asking questions that are to be answered from the data base.
Swatton and Pratt (1992) describe an investigation into paper helicopters using a database to immediately record measurement and observations of flight. Students are able to gain an understanding of what it is like to think and

work scientifically. Variables that affect flight were systematically explored and search strategies are used to identify factors contributing to a good flight.
Children's involvement in deciding upon the design of experiments, a framework for recording and questions for investigation is important for developing thinking skills. Knowledge, comprehension, application and analysis can all be developed as children learn to use databases independently to explore relationships, formulate hypotheses and test them by planning and printing reports (Ministry of Education and Training Victoria, 1991). The higher order thinking skills of synthesis and evaluation involve creating new perspectives and making judgements. They are more difficult to teach and require the use of abstract thinking which usually develops in secondary school (Watson, 1989).
Databases are also a useful way to organise information that is electronically exchanged between Australian and English children. One local project involved a comparison of information about food in their school canteens and plants in their school grounds.

3. Using a computer for remote control

A young child crouches, eyes glowing, mesmerised by a robot wandering around the room, eyes flashing and playing a tune as it turns itself around after bumping into something. Determination and pride in the construction of a sophisticated model of a car or happy exclamations as pushing a button at a door produce a jaunty tune are all examples of the powerful responses in children evoked by the use LEGO TC LOGO materials. The use of *LEGO TC LOGO* materials to make models using the computer for control and/or sensing is a logical extension of earlier experiences with construction activities and programming in Logo. Children work in small groups on a model that contributes to a whole class project, for example a ride for a fun park. Alternatively, projects are presented as design briefs as in Figure 2. Additional information including hints and sub procedures is provided to facilitate a solution

> There have been problems raising and lowering the flag at Parliament House.
>
> Design a system to help the Prime Minister raise the flag in the morning by pressing a button in his office, then lower it at night time.

Figure 2. Design brief

Many different creative solutions are developed by children. There are no right or wrong answers and individual interests can be pursued. The programming functions allow for the development of story lines and embellishments so that models respond in interesting ways to the commands of the computer. A solution to the design brief above includes a sub procedure for part of the Australian national anthem to be played when the flag reaches the top of the flag pole (Figure 3).

Science ideas can easily be linked to the models constructed increasing the relevance of the learning, for example, pulleys, gears, circuits and electric motors are commonly used. Worksheets guide the exploration of specific ideas and increase the background knowledge available for the development of solutions through designing, building and appraising.
Children work as practitioners of science translating scientific knowledge of machines, structures and computer control into practical knowledge (Layton, 1991). This needs to be supported by the teaching of a process for solving problems and the necessary skills to implement it (Yates & Moursund, 1988-9). In Figure 4 'WHAT PROBLEM is used as an acronym to define a process for problem solving.

```
to playtune
tone 392 4
tone 523 4
tone 392 4
tone 330 4
tone 392 4
tone 523 6
tone 523 2
tone 523 4
tone 659 4
tone 587 4
tone 523 4
tone 494 4
tone 440 4
tone 392 4
end
```

Figure 3. Sub procedure for tune (Povey & Vargo, 1993)

What specifically is the problem?
How might you go about fixing it?
Assess the different options available
Talk to the other members in your group

Proceed with the chosen option
Review the situation, is it working now?
Other options - do you need to try something else?
Backtrack to "A" if you do
Look at what you have now, are you happy with it?
Evaluate it - does it do what you wanted it to?
Make further adjustments.

Figure 4. Problem solving process (Lamb & Suffern, 1993)

The skills in thinking, the ability to construct models and the knowledge of computer control gained through fun projects in the elementary school establish a valuable foundation for further development. LEGO TC LOGO materials can be used to explore control technology commonly used in commercial/industrial settings including, robotic arms and assembly lines. The latter may be left more appropriately to high school years where vocational links become more important.

Conclusion

Although the full potential of computers in the science classroom still has to be realised, there already exist many glimpses of how computers can be used to aid science teaching and learning. The increased numbers of computers available for children to use, improved software packages and more teachers trained in the use of computers will all contribute to a transformation in the classroom where teachers will more often facilitate independent learning among their students

References

Arita, E. (1992). *Build a circuit.* Pleasantville, NY: Sunburst Communications.

Claris.(1991). *Claris Works.* Santa Clara, CA: Claris Corp.

Curriculum Corporation. (1994). *Science - a curriculum profile for Australian schools.* Victoria: Curriculum Corporation.

Fotopoulos, A. (1994). *The development of a science unit from a software package.* Melbourne: Deakin University, unpublished report.

Fox, H. (1986). Dragon World. *Classroom Computing*, 6(1), 3-7.

Fyfe, A. (1985). Possible uses of computers: the United Kingdom Example. 106-118 in Adams, F. (ed). *Science & Computers in Primary Education.* Edinburgh: Scottish Council for Research in Education.

Gilman, P. (1988). *The wonderful pigs of Jillian Jiggs.* New York: Scholastic.

Hartson, T. (1993). Kid-appeal science projects. *The Computing Teacher.* 20(6), 33-36.

Hartson, T. (1993). Rocks, minerals, databases and simulations. *The Computing Teacher.* 21(1), 48-50.

Hartson, T. (1993). The birds project. *The Computing Teacher.* 21(2), 31-32.

Inview. (1991). *A field trip to the rainforest* . Scotts Valley, CA: Wings for Learning.

Lamb, J. & Suffern, M. (1993). *Using LEGO TC LOGO to aid learning.* Melbourne: Deakin University, unpublished report.

Layton,D. (1991). Science education and praxis: the relationship of school science to practical education. *Studies in Science Education.* 19, 43-79.

Learningways. (1989). *Learn about animals.* Pleasantville, NY: Sunburst Communications

Learningways. (1992) *Muppet Labs* . Pleasantville, NY: Sunburst Communications

Malcolm, C. K. (1987).The Science Framework P-10. Victoria: Ministry of Education.

Matson, M. (1984). *Flowers of Crystal.* Barnstaple, UK: 4mation, Educational Resources.

Matson, M. (1986). *Dragon World.* Barnstaple, UK: 4mation, Educational Resources.

Microsoft. (1989). *Microsoft Works* . Redmond, WA: Microsoft.

Ministry of Education and Training. (1991). *What do you think?* Victoria: Education Shop.
Povey, B.. & Vargo, R. (1993). *Using LEGO TC LOGO to aid learning.* Melbourne: Deakin University, unpublished report.
Primary Science Project Team. (1981). *Science in the Primary School: Volume 1-5.* Victoria: Education Department.
Smith, F. E. & Olsen, C. L. (1986) *Bank Street School Filer.* Pleasantville, NY: Sunburst Communications.
Steinberger, M. (1993). Bridging the curriculum-technology gap. *The Computing Teacher.* 20(7), 39-40.
Swatton, P & Pratt, D. (1992). Helicopters, databases and the scientific process. *Primary Science Review.* 21, 8-11.
Watson, J. (1989). *Teaching thinking skills with databases.* Eugene, OR: International Council for Computers in Education.
Willing K. R. & Girard, S. (1993). Using theme related software. *The Computing Teacher.* 20(5), 24-26.
Wluka, G. (1984). *Raft-Away River.* Milton, Qsld: Jacaranda Wiley.
Yates, B. C. & Moursund, D. (1988-9). The computer and problem solving: how theory can support classroom practice. *The Computing Teacher.* 16(4), 12-15.

TECHNOLOGY FOR COMMUNICATION AND METACOGNITION

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Abstract: This study investigates the relationship between technology-mediated communication and the development of metacognitive abilities in elementary school children. A questionnaire was designed to assess students' self-perceptions as learners and of their own knowledge. Based on a similar methodology used in a previous study performed on an Italian sample, we compare two groups: a control group in which student did not use any technological communication versus an experimental group using technology to communicate for one year of science curriculum. The posttest performance of the younger children ($3^{rd}/4^{th}$ grade) in the experimental group shows that they perceive themselves as more actively involved in the process learning, but only within specialized contexts.

Metacognition is viewed as the ability to think about one's own knowledge and experience of learning and it has been recognized as an important factor supporting learning of new concepts (Brown, 1975; Baird & Mitchell, 1986; Pines & West, 1986; Brown, Bransford, Ferrara, & Campione, 1983), mediating conceptual change (Gelman & Brown, 1986; Chi, 1992; Gunstone, Robin Gray, & Searle, 1992; Roschelle, 1993) and monitoring of cognitive process such as memory, language and perception (Metcalfe & Shimamura, in press; Nelson, 1992). The present study was aimed at understanding what elementary school children consider to be important sources of information, how they perceive themselves as learners, and whether these perceptions can be affected after a year's curriculum of technological communication.

In a previous study performed on a large selected sample of Italian 3^{rd} through 6^{th} grade classes, (Caravita, Ligorio, & Palomba, 1993) we found that children's mental models of knowledge and how they perceive the process of knowledge acquisition were correlated with educational setting. In classes with directive teaching and a "traditional" curriculum, children conceived knowledge as something contained in encyclopedias, books, and adults. The educational setting engenders the belief that in order to know something, it is necessary to take it from outside sources and include it in one's own knowledge. In non-directive classrooms, technology provides classroom environments with the possibility of accessing information through different media, sharing their work products with peers, and widening the learner's community (Kaye, 1993).

Experimental Design

Fifty $3^{rd}/4^{th}$ grade students as well as forty-seven $5^{th}/6^{th}$ grade students participated in this study. The sample was divided into two groups. The control group consisted of two classes, one $3^{rd}/4^{th}$ grade and one $5^{th}/6^{th}$ grade neither of which had had any technological communication experiences. The experimental group was composed of two classes, one $3^{rd}/4^{th}$ grade and one $5^{th}/6^{th}$ grade, each of which had been using two pieces of software to communicate, QuickMail and CSILE, for one year. QuickMail is a child-friendly electronic mail package used to send electronic messages to children and teachers in other classes and to the university staff and elsewhere in the community (Campione, Brown, & Jay, 1992). CSILE (Computer-Supported Intentional Learning Environment) is a networked hypermedia system in which the database is wholly created by the students (Scardamalia & Bereiter, 1991). The aim of both systems is to promote higher level thinking, intentional learning and metacognitive ability. In the programs in which these systems were developed, children are viewed as able to inquire, understand and use knowledge in an independent way and to act as researchers.

The schools in which the present investigation was conducted are located in the inner city of Oakland, California. Most of the students can be described as academically at risk based on standardized scores. All

students were administered a questionnaire at the beginning of the scholastic year, as a pretest, and again at the end of the scholastic year, as a posttest.

The Questionnaire

Children's awareness about their roles and abilities can be considered as a good metric for assessing whether the goals behind introducing electronic communication to the classrooms have been achieved in our technology experimental classroom and if children's perceptions of knowledge and themselves as learners are correlated with the introduction of electronic communication.

The questionnaire used in the present investigation was designed to probe this awareness, and was previously administered to a large Italian sample (Caravita & Ligorio, Unpublished Manuscript). It was translated into English and tested on a pilot classroom. We choose to use an open-ended questionnaire because writing is a reflective practice and we take what children write as information about their conceptual development, individual knowledge, and social modeling (Edwards, 1992).

We developed the questions using a method of "trial and error". The final formulation of the questions, reproduced in the Table 1, was achieved through testing and adjusting them during the pilot study.

Table 1
The Questionnaire

1 - *What do you do when you want to know more about something?*

2 - *How do you know you really understand something?*

3 - *Imagine you are in a place where you have never been before and you find an animal that you have never seen before.*
a) What can you understand by watching at this animal?
b) What can you understand about that animal by looking at books?
c) If it were possible to keep this animal in your classroom, what would you do to get more information about that animal?
d) What would you ask experts to know more about that animal?
e) How can you use a computer to know more about the animal?
f) When do you think you know enough about that animal?

4 - *a) Tell us about the most important things you learned in science last year.*
b) What did you do to understand the things you learned in science last year?
c) Are you sure you understood everything you studied in science last year? Why?

The questionnaire was administrated in the classroom during the regular school hours. Children were requested to write what they really thought and to take as much time as they needed. They were told that there were neither right nor wrong answers to any of the questions.

Scoring Procedure

Responses to the questions were assessed with reference to two issues addressed by the present investigation: children's perception of knowledge sources and process and children's self-perception as learners. The following section will describe the procedure used to asses each of these dimensions.

Knowledge Sources and Process . Responses to Questions 1, 2, 4b and 4c were analyzed as relevant to students' understanding of knowledge sources and process. Three different kinds of answers were identified:

• Type I - External. This type of answer emphasized the external world. Children perceive knowledge as being outside of themselves. External sources quoted are media such as books, encyclopedias, TV, video, magazines, newspapers and computers, and people such as teachers, parents, experts, relatives, other children with more experience, and peers.

Example: *"I look it up in a book in the library or I can ask a grown up"*

• Type II - Internal & External. External and internal sources dialectically interact.

Example: "I *check what I did with one of my friends, if he does differently I ask him why he did it in that way".*

• Type III - Internal. This type of answer stresses that the internal world, one's own mental activity is in charge of learning and understanding.

Example: "I *think you would know how to keep it in your mind and it will stay there".*

Self-Perception as Learner. Students' self-perceptions as learners were probed by Questions 1, 3 and 4a. We identified two kinds of student responses: as student versus as scientist/researcher.

• As Student. No organizations of learning and understanding strategies were mentioned in Question 1. For Question 3, students were not able to identify, for each source and tool, the appropriate type of information. The criteria by which knowledge was evaluated were used on time and the quantity of information. Descriptions of what they learned in science (Question 4a) were either too general or too specific.

• As Scientist/Researcher. Strategies such as plans and topic differentiation were used to organize their own learning processes. Children are able to differentiate among tools and sources, quoting for each of them the appropriate information. Evaluation of their own knowledge is made by reporting relationships between causes and consequences. As salient concepts that they learned in science they report higher level thinking.

Results

With reference to children's views of their own knowledge sources, it was predicted that the experimental group's answers become less external on the cause of their participation in the program. It is also predicted that this group's self-perceptions as learners would be closer to scientist/researcher than the control group.

Analysis of variance reveal significant differences between groups only for the younger students of the experimental group and only for the answers referring to science learning. Responses to Question 4b reveal that the experimental group provided more internal answers than the control group. This results is marginally significant ($F(1,53)=3.65, p<.06$).

External answers decreased significantly ($F(1,53)=3.75, p<.05$) for the 3rd/4th grade experimental group in Question 4c. The same class was able, in Question 3f, to provide more explanations in terms of relationships between causes and consequences ($F(1,53)=5.62, p<.02$). In question 3e, this class provides more appropriate descriptions ($F(1,53)=7.1416, p<.01$) of how to use electronic communication.

Another interesting results is that the number of no answers (*"I don't know" "I don't remember"*) decreased for all the questions (for example $F(1,53)=7.26, p<.009$, in Question 4b). It appears that children became more aware of their own process of acquiring knowledge and of their role in that process, even if yet they are not able point out their owns internal sources.

Children's understanding of knowledge and themselves as learner can be considered high level thinking. For this reason it is not easy to effect change in this area during one year curriculum. We obtained a growth of type II and III answers for content specified questions. Questions content was about science because electronic communication was used in order to study this topic. We hypothesize that the metacognitive awareness we detected in the experimental group takes seed in a specific context and it may then grow to more general contexts. To verify this hypothesis it would be interesting to test classes where the electronic communication has been used for longer than a scholastic year.

Mastering the technology, such as that used by classes in this study, takes time in the part of teachers and students. Also, often technical problems take some time to be resolved. In addition, the software introduced in our experimental classes require deep reconstruction of the classroom (Scardamalia & Bereiter, in press) which could take more than a year to be really effective.

Results obtained from the Italian study (Caravita & Ligorio, Unpublished Manuscript) pointed out that electronic communication is not an easy tool to be used effectively and some preconditions have to be respected. For example, the class must spend time "preparing" to use electronic communication, understanding how it works and why to use it. Without these preconditions, electronic communication risks becoming another "external" knowledge source rather than a tool to compare and negotiate knowledge or a powerful tool with which reflect on one's own work and on the information obtained from other sources.

References

Baird, J.R., & Mitchell, I.J. (1986). *Improving the quality of teaching and learning: An Australian case study* - The PEEL Project. Malbourne: Monash University Printery.

Brown, A.L. (1975). The development of memory: Knowing, knowing about knowing, and knowing how to know. In H.W. Reese (Eds) *Advances in child development and behavior* (Vol. 10, pp. 103-152). New York: Academic Press.

Brown, A.L., Bransford, J.D., Ferrara, R.A., & Campione, J.C. (1983). Learning, remembering and understanding. In J.H., Flavell ,& E. M., Markman (Eds.) Handbook of child psychology: Vol. 3. *Cognitive Development* (4th ed., pp. 77-166). New York: Wiley.

Campione, J.C., Brown, A.L., & Jay, L., (1992). Computers in a Community of Learners. In E. de Corte, M. Linn, H. Mandl, & L. Verschaffel (Eds.), *Computer-based learning environments and problem-solving* (NATO Series, subseries F: Computer and System Sciences). New York: Springer-Verlag GmbH.

Caravita, S., Ligorio, M. B., & Palomba, F., (1993). "SCAMBI" per comunicare, produrre e riflettere: la Telematica a scuola. *Proceedings of DIDAMATICA '93*.

Caravita, S., & Ligorio, M. B. (Unpublished Manuscript) *Una indagine sulla rappresentazione metacognitiva della conoscenza in bambini di scuola elementare.*

Chi, M.T.H. (1992). Conceptual change within and across ontological categories: examples from learning and discovery in science. In R. Giere (Ed.), *Cognitive models of science: Minnesota studies in the philosophy of science.* Minneapolis, MN: University of Minnesota Press.

Edwards, D., & Potter, J., (1992). Discursive psychology, London, Sage.

Flavell, J. H., & Wellamn, H.M., (1989) Metamemory. In R.V. Kail. Jr., & J.W. Hagen (Eds.) *Perspectives on the development of memory and cognition* (pp. 3-33). Hillsdale, NJ: Erlbaum.

Gelman, R., & Brown, A.L. (1986). Changing views of cognitive competence in the young. N.J. Smelser & D.R. Gerstein (Eds.), *Behavioral and social science: Fifty years of discovery* (pp. 175-207). Washington. DC: National Academy Press.

Gunstone, R.F., Robin Gray, C.M., & Searle, P. (1992). Some Long-term effects of Uniformed Conceptual Change. *Science Education* 76, (2), 175-197.

Kaye, R.A., (1993). Learning Together Apart. In *ASI Series Books. Collaborative Learning Through Computer Conferencing.*

Ligorio, M. B., (in press). "Community of Learners": strumenti e metodi per imparare collaborando. *TD Tecnologie Didattiche*

Ligorio, M. B. (1993). Tecnologia, comunicazione e metacognizione. *Golem* n.2/3.

Linn, M.C., & Songer, N.B., (1993) How do students make sense of science? *Merril-Palmer Quarterly*, 39(1), 47-73.

Metcalfe, J., & Shimamura, P., (in press). *Metacognition, Knowing about Knowing.* MIT Press Cambridge, Massachusetts, London, England.

Nelson, T.O., (1992). *Metacognition: Core readings.* Boston: Allyn & Bacon.

Pines, A.L., & West, L.H.T. (1986). Conceptual Understanding and Science Learning: An interpretation of research within a sources-of-knowledge framework. *Science Education*, 70, 211-227.

Roschelle, J., (1993). Learning by Collaborating Convergent Conceptual Change. *The Journal of the Learning Science*, 2 (3), 235-276. Lawrence Erlbaum Associates, Inc.

Scardamalia M., & Bereiter, C. (in press). *Computer Support for Knowledge-Building Communities.*

Scardamalia M., & Bereiter C. (1991). Higher levels of Agency for children in Knowledge Building: A challenge for the Design of New Knowledge Media. *The Journal of the Learning Sciences*, 1 (1), 37-68.

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How to make CAI fail

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Abstract: Long after it was first shown that computer-assisted instruction can be a useful learning tool in a variety of areas including the sciences, CAI has received only miniscule acceptance as a significant tool for mainstream academic instruction. While there are many who are open to innovations in instruction, it would appear that a majority of college-level instructors would just as soon carry on as they have in the past. This paper is addressed to both groups: for the dinosaurs, it is a guide on how to run CAI into the ground; others should read it as a caution on how CAI easily can fail even with the best of intentions.

Computers have revolutionized nearly every endeavor to which they have been applied except for one: education, at both the school and post-secondary academic levels, has largely managed to resist this innovation, as it has so many others. Some of the more forward-looking academic chemistry departments provide their more advanced students with a variety of software for spreadsheet calculations, plotting, NMR analysis, equation solving and molecular modeling, but seem almost purposefully to avoid applying computers to the task of mainstream instruction. This is curious in the light of over twenty years of experience which has shown that CAI can be not merely an *adequate* tool for delivering instruction in many areas, but in many cases a decidedly *superior* one. At the same time, numerous studies have concluded that one would be hard put to devise methods of instruction that do a poorer job than conventional lecture-based instruction in helping students to assimilate information and learn concepts.

It is worth noting that CAI seems to have gained wider acceptance in industrial and military training; it may be significant that in these areas, the students are being paid a salary while learning, so the employer has a direct interest in getting students to meet specified performance criteria in the shortest possible time. In academic education, by contrast, our students pay *us* for their courses, so that the same efficiencies that make CAI attractive to industry would be disincentives in academe if we were foolish enough to actually allow them to be realized.

Of course most schools have long used computers for the really important functions such as administration and scheduling, and to most researchers computers are an indispensable tool, if only for E-mail and database searching. As technology marches on, however, there is increasing pressure to make better use of computers in the instructional process. Although educators as a group have demonstrated a remarkable ability to resist innovation, increasing numbers are beginning to weaken, and it is clear that the remainder will soon need some good arguments to preserve their hallowed practices. What better argument than to show that CAI simply does not work? Although CAI definitely does work for my own classes, this could simply be the result of my having the wrong attitude, in believing that it *can* work, and in taking steps to *make* it work. For those who hold different views (or simply want to get on with other activities and not be bothered having to think much about teaching), I offer the following suggestions which reflect about twenty years of personal experience.

- First, and most important, make sure you have a well-equipped computer lab. The more committed you are to 19th century instructional methods, the more important it is to deflect criticism by maintaining a year-2000 appearance. If you teach in a public school, say that the computers are there for "enrichment", which consigns them to a limbo into which you and your students need never enter. In a college chemistry department, install word processors and spreadsheet programs; students will quickly sense the unpleasant associations with writing English prose and with physical chemistry, and will visit the computer room as little as possible.

- At the beginning of the semester, announce that CAI lessons are available for students who wish to use them or who need extra help. The students will interpret this as "CAI lessons are available for those who are dumb and want to do extra work" (to many, the latter proves the former). No self-respecting student will go near the computer lab.
- Treat CAI as an "instructional aid", rather than as a part of the mainstream instructional process. This is best accomplished by continuing to give lectures and assignments as if CAI did not exist. Guard against the temptation to curtail lecture treatment of topics that are better conveyed by CAI; stick to those venerable 1970s-era lecture notes!
- Continue to collect and mark homework problems in the traditional way, even if lack of TAs allows marking of only two out of ten problems. By the time the marked papers are returned, the student will likely be preoccupied with the next week's assignment and will not pay much attention to whatever feedback is provided, but this is how things have always been anyway. Avoid exposing them to lessons that provide instant feedback and actually try to get the students to think about what they are doing; they might start asking for similar tools in the more advanced courses that you hope to give as soon as you can get out of freshman teaching.
- Specify a textbook costing over $75 and weighing at least 2.5 kg; the particular title is of no importance, since their design and editing is now controlled by the same MBA's in marketing anyway. The point is to make the text such a large investment both economically and in the physical effort of lugging it around, that students will value it more than the CAI lessons which can't be as useful because they are free.
- If you employ TAs, keep them away from the lessons. Their ignorance of them will reinforce the impression by students that the CAI material is unimportant, and will reduce the likelyhood that the TAs will themselves look kindly on CAI when they go on to become instructors.
- Select awkward, hard-to-use courseware. If you use IBM-type computers, make sure that the lessons operate in 40-column CGA mode, which evokes a kindergarten-like image. If students must type in formulas, the program should not accept answers such as "H2PO4–", but should require the student to enter proper subscripts and superscripts by pressing Ctr-Esc-right-Shift-Alt-F9 or some other easily-recalled mnemonic. Above all, the lesson should discourage quitters by providing no apparent way of escape until the student has reached the bitter end.
- The lessons themselves should have been designed by Education Specialists, who are more likely to employ well-established response-reinforcement techniques. For example, *Statement:* "Fire engines are red." *Question:* "What color are fire engines?" B.F. Skinner used this technique with great success to train pigeons, who are evidently immune to boredom. This will turn away all but your most unimaginative drudges.
- Multimedia technology can be highly valuable in producing lessons that look (and sound) impressive and whose preparation efficiently consumes grant funds (which categorize your work as "research" rather than teaching), but which can nevertheless be almost completely devoid of real educational content without anyone being the wiser.
- Discourage students who have computers of their own from getting copies of the software for use at home; such students are likely to be the most enthusiastic proponents of CAI, and may thus become a disruptive influence.
- Recommend CAI to colleagues as a means of improving their teaching. This insult will guarantee a united faculty front against this newfangled nonsense.
- Recommend CAI to deans and administrators as an excellent addition to instruction. They will interpret this as an additional cost item that can be removed from next year's budget, thus going a long way toward solving your problem right there.

These are only a few of the stratagems one can employ to delay the inevitable; if all else fails, there is always early retirement!

A Tutoring System for Discovering Plane Geometry using Tangram

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Abstract

This paper discusses some issues about a tutoring system as a useful tool in the mathematical learning/teaching process. In particular it is proposed a tutoring system based on Tangram, a millenary Chinese game that provides a large number of activities that lead the students to the construction of geometric concepts. The learning process in which students and teachers are active participants is emphasized. It is also proposed a cooperative environment so that the student/teacher dialogue is strongly stimulated. The tutoring system is proposed so that it would never substitute the teacher in her/his tasks. The system is supposed to be a support tool in the teaching/learning process.

1 Motivation

It is well known that the utilization of computers in education is always increasing. It is important, however, to emphasize the computer's task in situations where it supposed to be a complementary tool in the teaching/learning process - not an automatized tutor that transmits information to the student nor a teacher's substitute. It should be considered as a helpful tool in the reasoning development, favoring the intuitive though of the learner. It must be seen as a tool to provide the formalization of the intuitive concepts acquired by the student. So, the learning process must come to mind through activities made by the student, not just by transferring information from the computer and/or the teacher to her/him.

Although it is really helpful, the computer cannot be seen as a panacea of educational problems (Nunes, Mendes, & Andreucci, 1993; Epstein, & Hillegeist, 1990). By itself it means almost nothing; it needs a strong educational basis to support and give information about relevant points of the teaching/learning process. For example, it is absolutely necessary to know the more frequent problems related to the matter as well as the appropriate activities for each student in each moment. Another important point is the profile of the student who is interacting with the system. So, the computer must be seen as an additional element in the educational environment to favor different drills that are consonant with the student's aptitude, previous experiences, rhythm and preferences.

The construction of the concepts comes from an interior reflection that takes place when the student thinks about the drills she/he has done. Such process leads the student to the interiorization of the actions. In this sense, it is known that appropriate games can be important elements to motivate the students in an interesting and creative way. Specially in Mathematics the games have been seen as a good resource. This way the computers can be strong allies to avoid the frequent aversion children have

about Mathematics, one of the most insistent problems in Math education. The literature has plenty of studies concerning the benefits the games can bring in the teaching/learning process (Jamski, 1989; Barron, & Kantor, 1993).

2 Aim

This paper presents the project TEGRAM - an intelligent tutoring system for learning concepts of plane geometry to be used by elementary school students. It consists of practical activities involving concepts of plane geometry. These activities are presented according to the student profile and to a teaching strategy that distinguish the learning by discovery. This way the student is lead to discover, through activities, the concepts that the system intends to teach. TEGRAM works in an intelligent way since it provides an individual learning based on students feedback. The system has a mixed initiative control: it does not restrict the student to a fixed sequence of tasks, neither let her/him too free to hinder a reasonable teaching plan.

To motivate the students for exploring the concepts to be taught, all the activities are based on the Tangram, a millenary Chinese game (Santos, & Imenes, 1987; Güngördü, & Oflazer, 1991). It consists of seven parts: 5 triangles, 1 square and 1 parallelogram. All of them were originated from the decomposition of the whole square as shown in Figure 1.

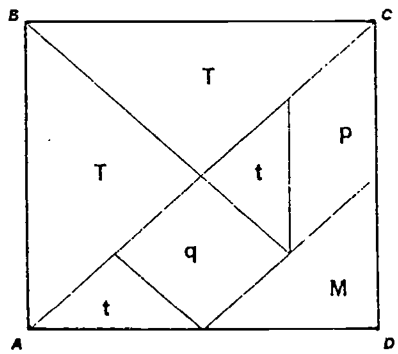

Figure 1. Tangram.

There are countless didactic activities based on Tangram that can be explored for children and students of different ages and school levels (SE/CENP, 1988). The range varies from tasks of identification of shapes, figures, angles, to tasks involving classification and construction of plane geometry figures, congruence and similarity among figures, concepts of area and length.

The underlying idea is that the student can assimilate these concepts in an intuitive way, throughout a guided realization of the system activities. The formulation of the concepts would be achieved only *a posteriori*.

3 The System Architecture

The TEGRAM system consists of four classical components: the **domain module**, the **student model**, the **tutorial module** and the **communication module** (Wenger, 1987; Nwana, 1990; Burger, & Desoi, 1992) (Figure 2).

The **domain module** has the knowledge of the topics to be taught. It is divided into a **concepts network** and a **definitions network**. A subgraph of concepts to be presented is selected according to the student model. A concept can be considered nuclear (N) - if it involves major ideas - or satellite (S) - if it involves complementary ideas. Nuclear concepts consist of all subject topics TEGRAM can teach.

For example, if the nuclear concept is the notion of area (Mendes, 1989), the following activity ilustrates those that may be presented (Figure 3):

In this case there are some fundamental geometric concepts that may be called **satellite ideas.** Suppose that the student starts the activity by discovering the small square area. So some satellite ideas are:

- The hole is the sum of the parts.
- The diagonal of a square cuts it in two triangles.
- Those triangles are rectangles, isosceles and congruents.

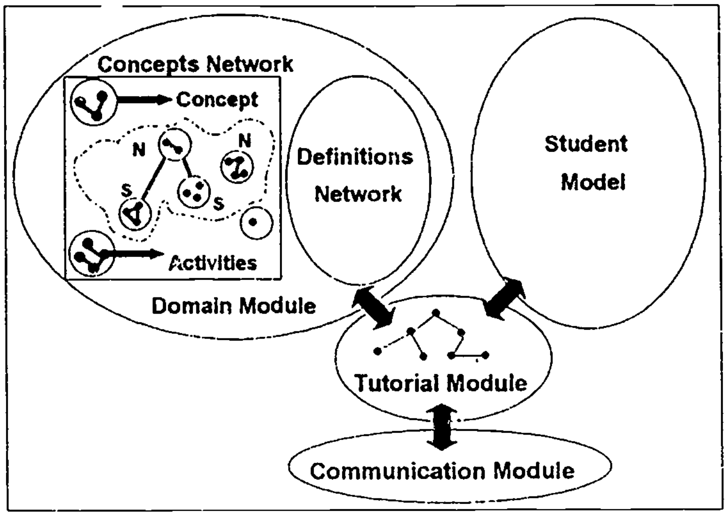

Figure 2. The TEGRAM's architecture.

For the other shapes, analogous ideas could be presented. Shall we say for one of the big triangles:

- The hole is the sum of the parts.
- The big triangle is covered by the small square and two small triangles.
- The big triangle is covered by two small triangles and one parallelogram.
- The big triangle is covered by one midle size and two small triangles.
- The parallelogram is covered by two small triangles.
- The midle size triangle is covered by two small triangles.
- The small square is covered by two small triangles.

Each **nuclear concept** originates an **activities network** which is submitted to the student so that the order is established according to the student model. Depending on the student performance during an activity, the tutor can indicate some revision or a related activity that will better cover the detected problems.

The **definitions network** consists of the knowledge about the geometric figures that are the Tangram's parts: square, small triangle, midle size triangle, big triangle, parallelogram and all of the possible combinations of them to generate other geometric shapes.

The **student model** is dynamically updated with information given by the student's choice about the activities (Elsom-Cook, 1993). It is also updated by the activities and concepts the student has covered, the student performance and the detected problems in each activity.

The **tutorial module** is a production system that combines knowledge from the domain module and the student model to selected the material to be presented to a student. The main underlying strategy

is to guide the student through a reasoning path that can lead her/him to formulate an unknown (for her/him) concept.

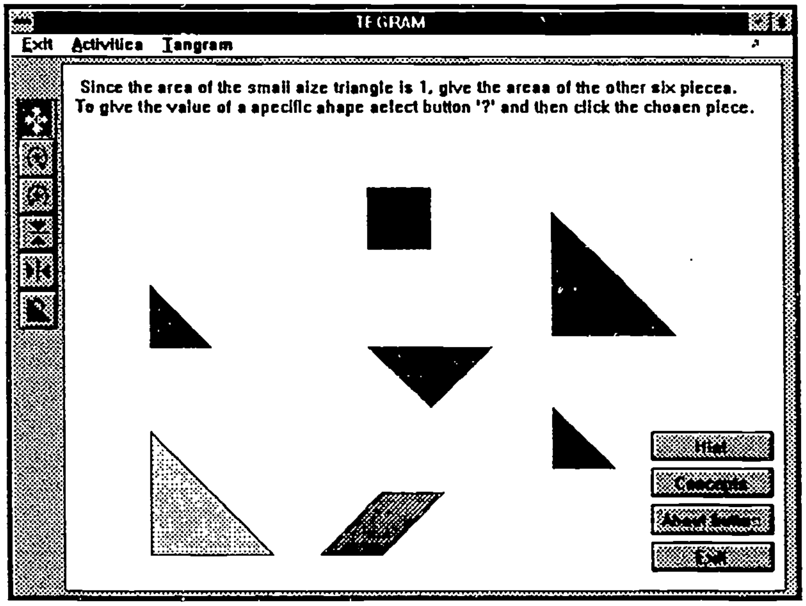

Figure 3: Activity about notion of area.

The main feature of the **communication module** is its graphical facilities, since TEGRAM is supposed to be used specially by children. Most of the activities are presented so that the problem is stated in one window and the solution has to be built in a lower one. Both of them are supplied by graphic resources for figures movements. A work window for text editing is also available for the student. The figure below illustrates one of the TEGRAM's activities.

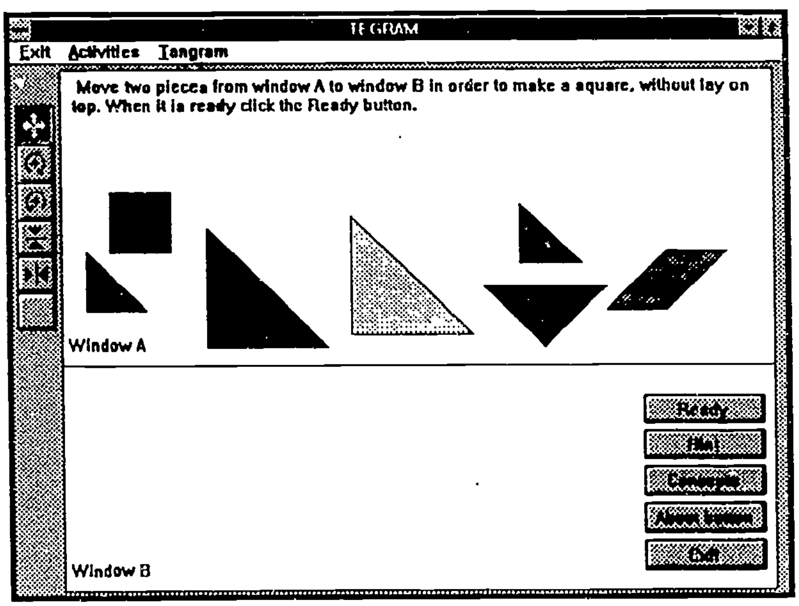

Figure 4. Activity for construction of geometric figures.

References

Barron, B. & Kantor, R.J. (1993). Tools to enhance math education: the JASPER SERIES. *Communications of the ACM*, 36(5), 52-54.

Burger, M. & Desoi, J. (1992). The cognitive apprenticeship analogue: a strategy for using ITS technology for the delivery of instruction and as a research tool for the study of teaching and learning. *International Journal of Man Machine Studies*, 36, 775-795.

Elsom-Cook, M. (1993). Student modelling in intelligent tutoring systems. *Artificial Intelligence Review*, 7 (3-4), 227-240.

Epstein, K. & Hillegeist, E. (1990). Intelligent instructional systems: teachers and computer-based intelligent tutoring systems. *Educational Technology*, (11), 13-19.

Güngördü, Z. & Oflazer, K. (1991). Solving tangram puzzles. In: *ISCIS VI - International Symposium on Computer and Information Science*. Side, Turkey. Proceedings. Turkey, 6, 691-702.

Jamski, W. (1989). Six hard pieces. *Arithmetic teacher*. 34-35.

Mendes, M.D.C. (1989). *The notion of area: possible ways of learning.* (In Portuguese). PhD thesis, Universidade Estadual de Campinas/UNICAMP. Brazil, 160p.

Nunes, M.G.V, Mendes, M.D.C. & Andreucci, C.A. (1993). Some issues on learning mathematics through intelligent tutoring systems. In: *Seventh International PEG93 Conference - PEG93 - AI Tools and classroom: Theory into Practice*. Edinburgh. Proceedings. Edinburgh, I, 189-202.

Nwana, H.S. (1990). Intelligent tutoring systems: an overview. *Artificial Intelligence Review*, 4, 251-277.

Santos, C.H. & Imenes, L.M.P. (1987) TANGRAM: an old Chinese game in Mathematics classrrom. (In Portuguese). *Revista do Ensino de Ciências*, 18, 42-49.

SE/CENP. (1988). (In Portuguese).*São Paulo Department of Education. Elementary School Mathematics Curriculum Proposal.* São Paulo, 140p.

Wenger, E. (1987). *Artificial intelligence and tutoring systems: computational and cognitive approaches to the communication of knowledge.* Los Altos, California, Morgan Kaufmann Publishers. 486p.

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Computer Literacy: A Global Perspective

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Abstract: The advent of the Information Superhighway and the introduction of the personal computer into the classroom has changed the definition of computer literacy. In this paper, we want to examine aspects of computer literacy and present a new definition applicable to teacher education.

INTRODUCTION

The discussion of the Information Superhighway and the increased role of computers in all areas of life show how important it has become for children to be prepared for the fast changing world. It is also obvious that for children to be computer literate, their teachers must be computer literate as well. At the same time, the meaning of the term "computer literacy" appears to be changing as fast as computer technology itself (see Duckett, 1992).

Since 1992, we have been involved in studying various aspects of computer literacy and its application to teacher education (Mitchell & Paprzycki, 1993; Paprzycki, Mitchell & Duckett, 1994). In this paper we wish the results of our current study on the perception of the role of computer literacy as it relates to teacher preparation and discuss the implications these results present for teacher education.

SURVEY METHODOLOGY

During our studies, we took advantage of the increasing use and availability of global computer networks. We used selected listservs to disseminate our survey questionnaires. To increase the number of responses, data was collected twice (during early fall, 1992, and late spring, 1993). Because of the length of the survey, it was split into two parts with the first part being sent to the selected listservs and the second part being sent to interested individuals. A detailed description of the research methodology has been previously discussed (Mitchell, Paprzycki, & Duckett, 1994).

SURVEY RESULTS

A total of 76 individuals from 12 countries (Australia, Brazil, Canada,Germany, Ireland, Israel, New Zealand, Poland, Puerto Rico, South Africa, Turkey and the United States) responded to the first part of the

survey; 69 responded to the second part of the survey. Fifty-eight of the 76 participants were teachers or lecturers. Sixty-five were involved at the university or college level with an average of 17 FTE in the various departments. An average of 5 FTE were involved in teaching "Computers in Education" issues courses. 52 of the participants had some form of training with computers or with "Computers in Education" issues.

The respondents indicated that there are limited requirements for individuals to be computer literate prior to becoming certified. Nineteen of the respondents indicated that there was a computer literacy requirement for teacher certification; 15 indicated that computer literacy was at least recommended. Twenty-one indicated that a computer literacy requirement was not being considered at this time.

These results do suggest that this requirement is increasing or that more programs are requiring/recommending a computer literacy element in the teacher certification process. This result is also corroborated by the data in Table 1 where the clear concern about computer literacy is indicated as part of

Table 1 Concerns for Computer Literacy

Level of concern	Great concern	of some concern	concern	little concern	no concern	no answer
in general	26	22	11	12	1	4
as part of teacher education	18	23	11	14	2	8

teacher education and even more so as a general education requirement.

Participants in the study were asked to indicate the degree of their current situation with regards to the learning of skills and/or knowledge of the subject as it is currently being taught and how they would prefer it to be taught. The results indicate that there is a shift from a marginal inclusion of computers in the curriculum to a major incorporation of materials (see Table 2).

Previously, we determined that the actual definition of computer literacy depended on who made the definition and in what context the definition was being made. In the second part of this study, we sought to identify the specific parts of the computer literacy definition. As indicated in Table 3, respondents felt that computer usage and the inclusion of computers into the overall curriculum is a low priority at the present time. Respondents also indicated that there should be a high priority on such usage. The results also suggest that part of this curriculum should be prior to pre-service teacher programs, i.e., the general education curriculum. Finally, with respect to teacher education programs, the results suggest that there should be a shift from the development of an understanding of the computing process (programming languages and the physical setup of computers) to one of an understanding of how to use computers in a number of settings. Also, teachers should be able to evaluate software for its application to education settings rather than being able to prepare or develop such software.

CONCLUSIONS

The recent discussion in the United States for an information superhighway will have a dramatic impact on teacher education. It has already been documented that many teachers have to turn to their students for information about computers. The results of this study suggest that the current emphasis on computer literacy does not match the direction computer usage will take in the coming years. The results also suggest that teacher education programs should focus on the development of skills that allow teachers to use computers more effectively and efficiently.

Table 2 Computers as part of the curriculum

Key to responses

1 = No emphasis 2 = A little emphasis 3 = Moderate emphasis 4 = Strong emphasis

		Currently Taught				Prefer to See Taught			
		1	2	3	4	1	2	3	4
1)	The use of computers in education is incorporated into curriculum studies where applicable.	10	33	18	6	1	0	16	50
2)	Computer literacy as a requirement for teacher certification.	34	18	11	5	4	5	27	32
3)	Computer literacy as a required subject for pre-service teacher education.	30	23	4	10	4	5	20	38
4)	Students are encouraged to learn computer skills in their own time.	9	26	25	9	3	9	28	29
5)	Students are taught computer skills as part of course work.	10	32	18	9	2	2	19	46
6)	Students are encouraged to use computers whenever it applies.	13	28	19	9	1	0	16	52
7)	Students are encouraged to word process assignments in preference to turning in hand-written ones.	5	32	19	13	1	3	18	47

REFERENCES

Duckett, G. (1992) Basic Problems in the Development of a Computer Literacy Curriculum, ACED '92 Computing in the Clever Country, Computer Education Group of Victoria, Richmond North, Victoria 3121, 283 - 318.

Mitchell, T. & Paprzycki, M. (1993) Teaching New Technologies: Developing a Computer Literacy Course for Prospective Teachers, Proceedings of the Sixth Annual Southeastern Small College Computing Conference, Journal of Computing in Small Colleges, 8(3), 65.

Mitchell, T., Paprzycki, M., & Duckett, G. (1994). Research Methods Using Computer Networks, Electronic Journal of Virtual Culture, in press.

Paprzycki, M., Mitchell, T., & Duckett, G. (1994). Using Computer Networks to Study Computer Literacy, Technology and Teacher Education Annual - 1994, AACE, Charlottesville, 1994, 91 - 93.

Table 3 Components of Computer Literacy

Key to responses
1 = No emphasis 2 = A little emphasis 3 = Moderate emphasis 4 = Strong emphasis

		Currently Taught				Prefer to See Taught			
		1	2	3	4	1	2	3	4
8)	... influence and impact of computers on society.	21	28	18	0	4	11	33	19
9)	... software applications	8	25	24	12	0	5	24	39
10)	Requiring pre-service teacher education students to be computer literate upon entry into service teaching	19	25	17	7	2	2	24	39
11)	... setup computer equipment and load software.	21	29	11	8	1	10	29	29
12)	Knowledge and ability to use a computer network.	29	24	10	5	5	12	31	20
13)	Develop the knowledge of and the ability to use e-mail.	27	20	15	7	2	3	25	39
14)	Legal implications of software copyright abuse.	30	26	10	3	6	8	30	25
15)	Use of computers and software in the curriculum.	17	27	14	10	3	5	15	45
16)	Using computers as an administrative tool.	20	31	15	2	6	9	24	29
17)	A criteria to measure the competence of computer usage.	36	18	7	3	7	18	22	17
18)	The effect of computers on education outcomes.	27	32	7	1	7	18	25	17
19)	The use of the computer as a teaching tool.	18	27	18	3	4	3	19	39
20)	Using computers to solve problems.	23	29	12	5	1	4	32	31
21)	What is a computer and how does it work?	27	26	14	2	3	29	31	6
22)	Evaluation of educational hardware and software.	32	24	8	5	0	9	33	27
23)	Ability to use an authoring software package.	33	19	10	4	5	14	23	21
24)	Emphasis on the study of high level computer programming languages	19	25	11	13	12	14	15	25
25)	Documentation of instructional software	24	33	8	2	7	16	26	17
26)	The use of computer-assisted instruction.	23	35	8	0	6	10	36	14
27)	The use of computer-managed instruction.	24	24	11	5	5	13	31	15

The Little Inference Engine That Could

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Abstract: The "little inference engine" is ET, "The Expert Turtle," a backward chaining expert system shell written for *LogoWriter™ 2.00* for DOS. ET4 is the latest in a series of ET versions starting in 1985 with a version for IBM Logo that was essentially a translation of a LISP program. ET4 has an improved user interface that allows users to write expert systems using the words of ordinary logic (GOALS, RULE, IF, THEN, AND, NOT). A compiler converts inputs into Logo language which are then used by ET4. An important feature of ET4 is that it supports EVAL and RUN commands. In an IF clause the EVAL function evaluates a user-written Logo boolean function. In a THEN clause the RUN command executes a user-written Logo procedure. ET is presently used in master's courses for mathematics and science teachers. Copies of ET4 along with documentation are available from the author.

Description of ET4

ET4 is a backward-chaining, expert system shell written in *LogoWriter™ 2.00* for the IBM. The knowledge base used by ET4 comprises Logo language MAKE statements, but users can create knowledge bases in a simpler, production rule language, ETPRL, commonly found in other shells. The ETPRL file is converted to Logo language statements by a compiler written in C. An example of ETPRL is shown in Figure 1, which illustrates the use of all ETPRL commands (always capitalized) except NOT, RUN and EVAL. RUN and EVAL will be discussed with an example (Figure 2) later.

ET4's inference engine

The inference engine performs multiple searches to establish one of the GOALS. Treating the GOALS list as a queue, it selects each in turn until one is proven. Once a goal is chosen the inference engine first searches a list of established facts (@FACTS) to see if the goal is already proven. If the goal cannot be found among established facts, then the inference engine searches the knowledge base itself - the rules (whose names, RULE1, etc., are stored internally in a list named @RULES), gathering into a stack all rules having some THEN clause matching the goal. Whenever a goal cannot be found among any THEN conditions, the user is asked to affirm or deny ("Is this true?:") the goal.

```
COMMENT A knowledge base for particle physics
GOALS
The particle is a hadron.
XOR The particle is an electron.

RULE for hadron
IF The particle is a baryon.
AND The particle comprises three quarks.
THEN The particle is a hadron.
AND The particle is a constituent of the nucleus.

RULE for electron
IF The particle is a lepton.
AND The particle was discovered in 1897.
THEN The particle is an electron.
AND The particle is in a shell surrounding the
nucleus.

RULE for baryon
IF The particle is heavy.
AND The particle has spin 1/2.
THEN The particle is a baryon.

RULE for lepton
IF The particle is light.
AND The particle has spin 1/2.
THEN The particle is a lepton.
END
```

Figure 1 An example of knowledge base written in ETPRL

The inference engine is not only goal-directed, it also supports *backward chaining*. This means that each of the IF conditions in a rule also becomes a subgoal, and the same search process outlined above for the top-level GOALS is conducted for subgoals. Thus a stack of rules satisfying subgoals may be built. The last two rules in Fig 1. are examples of backward chaining. Neither rule satisfies a top level goal (proton, neutron, electron). Instead the rules satisfy two subgoals among the IFs of the first three rules. (The actual order of the rules in the knowledge base is not logically significant.)

The principle purpose of the inference engine is establishing consequent (THEN) facts by establishing antecedent (IF) facts. All proven propositions are put into a list of facts (@FACTS). However, the EVAL and RUN commands add to the engine's versatility. When an EVAL is encountered as an antecedent, the engine does not perform a search, but rather evaluates the user-written boolean function identified on the EVAL line. This function

could obtain input from various kinds of inputs (memory, keyboard, ports). When EVAL is used nothing is automatically added to @FACTS, but the user-procedure can do so explicitly (MAKE "@FACTS ...).

When a rule is fired (i.e., all antecedents are proven), the main purpose is to add a fact to @FACTS (and to be finished if the fact is a top-level goal). However additional consequents can be conjoined (ANDed) which might be additional facts or, if a RUN command is encountered, a request to execute user-written procedures. A procedure so executed can also update the @FACTS by explicit code (MAKE "@FACTS ...).

ET4's Production Rule Language (ETPRL)

The following commands compose ETPRL: GOALS, RULE, NOT, AND, IF, THEN, END, XOR, EVAL and RUN. XOR can only be used as a separator of goals and is meant to imply that the goals are mutually exclusive. In fact this restriction is easily overridden when a THEN contains the conjunction of two or more goals.

There is no explicit OR command, but or conditions are easily simulated when two or more rules have the same consequent (*IF a OR b THEN c* is equivalent to *IF a THEN c* and *IF b THEN c*). XOR cannot be used within rules, but it can be simulated by using NOT in two rules (*IF a XOR b THEN c* is equivalent to *IF a AND NOT b THEN c* and *IF b AND NOT a THEN c*).

EVAL and RUN

Through the use of EVAL and RUN commands the user can provide an interface to user-written Logo functions and procedures. The EVAL command is used only on the antecedent (IF) side, in as many conjunctive clauses as desired, with "reporter" functions which output either true or false. Sometimes, in the spirit of PROLOG programming, the reporter function might be used only for its procedural side-effects, always outputting true. In other cases the function make be a true boolean function, establishing the truth or falsity of some conditions. For example, the function could interrogate a port connected to an outside device, such as a temperature probe or robot sensor.

The RUN command can be used only on the consequent (THEN) side, in as many conjunctions as desired. It can be followed by Logo commands or the names of user-written procedures. Figure 2 shows an example of a ETPRL knowledge base along with a reporter function (getparams) and a procedure (solvequad).

The History of ET

The first version of ET was written in 1985 (Murphy, 1985) for IBM Logo. At that time there were no commercially available shells for low cost, and a shell was needed for an expert systems class taught by the author. The original version was essentially a translation into Logo of a backward chaining algorithm presented in Chapter 18 of Winston

```
COMMENT An expert system for solving quadratic equations
GOALS
The quadratic equation is solved.

RULE To get and solve a quadratic equation
IF EVAL getparams
THEN The quadratic equation is solved.
AND RUN solvequad
END

to getparams
print [Input the parameters A, B, and C ]
print [of the quadratic equation]
print [of the form AX^2 + BX + C = 0]
make "paramlist readlist
output "true
end

to solvequad
make "complex "false
make "a first :paramlist
make "b first bf :paramlist
make "c last :paramlist
make "term1 :b * :b
make "term2 :term1 - 4 * :a * :c
if :term2 < 0 [make "complex "true make "term2  0 - :term2]
make "term3 (sqrt(:term2)) / (2 * :a)
make "term4 0 - :b / (2 * :a)
ifelse :complex [print [The solutions are complex] print (se [X1 =
] :term4 "+ :term3 "i) ) print (se [X2 = ] :term4 "- :term3 "i]
[print [The solutions are real.] print (se [X1 = ] :term4 + :term3)
print (se [X2 = ] :term4 - :term3)]
end
```

Figure 2 An example of the use of EVAL and RUN in a knowledge base

and Horn's first edition of *Lisp* (1981). One of the most difficult things in the translation was that although Lisp and Logo are similar list-processing languages, Lisp is a functional language, while Logo is not. This original version had a menu-driven interface, but users had to work directly with Logo PPROP statements. Since property lists couldn't be edited with IBM Logo, a version using MAKE statements was developed, and it is these MAKE statements that compose the knowledge bases of all subsequent versions.

The first *LogoWriter* version was written in 1991. At that time the ETPRL was added as a user-friendly form of input, mimicking the kind of input found in commercial products, such as *Level 5*™. One problem with *LogoWriter* as compared with IBM Logo is that the latter can read data files, while the former can only read files of procedures. The solution was to have the compiler for ETPRL output a file consisting of one procedure (TO @KB), and this procedure contains all of the MAKE statements to create the knowledge base within Logo. When ET4 is given the name of a compiled file, it reads the file and executes @KB. The most recent version, ET4, has the added EVAL and RUN commands which gives ET the power to run user-written Logo procedures. These procedures can, for example, input from or output to ports, etc.

The Use of ET in Teaching Mathematics and Science

Versions ET2 and ET3 have been in use in the author's master's classes for teachers of science and mathematics since 1991. The emphasis has never been placed on using ET as computer software to replace the many excellent CAI programs available. Instead, the purpose of teaching and using ET is to see how logical thinking, of the kind found in science and mathematics, can be modelled. One of the most important things to note is not how *good* the system is for modelling thinking, but how *bad* it is. The starting point for discussion is the definition of intelligence given by Allen Newell (1990): "Thus, intelligence is the ability to bring to bear all the knowledge that one has in the service of one's goals" (p. 90). Students are made aware, for example, that perfectly good rules which do not satisfy system goals, can never be used by ET. In other words, the knowledge may be there, but the ability to use it is missing.

More fundamental is the fact only lexical matching is done, so that ET cannot determine that two ways of saying something may represent equivalent events (e.g., "Jim threw the ball" vs "The ball was thrown by Jim"). This can lead to discussion of the sophisticated match functions used by scientists and mathematicians. For example, under certain conditions mechanical and electrical systems can be regarded as identical in their behavior. Finally, ET cannot learn, form different representations, or make its own rules. None of these discussions of ET's weaknesses has the intention of deprecating ET, but instead to respect the fineness of human intelligence. The purpose of ET remains as just one way of looking at and playing with knowledge, and not as a replacement of the many fine CAI programs for teaching science or mathematics.

Copies of ET4 along with documentation are available from the author.

References

Murphy, D. (1985, December). *The little inference engine that could.* Paper presented at the Florida Instructional Computing Conference, Orlando, FL.

Newell, A. (1990). *Unified theories of cognition.* Cambridge, MA: Harvard University Press.

Winston, P. H., & Horn, B. K. P (1981). *Lisp.* Reading, MA: Addison-Wesley.

LEARNING CHEMISTRY THROUGH COMPUTER MOLECULAR MODELING

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ABSTRACT: The technique of computer molecular modeling can provide added insights into molecular structure, structure-activity relationships, and energy correlations in molecules in both their excited and ground states. It can be very effective in teaching many of the concepts which are presently taught in general and organic chemistry. Instructions for using molecular modeling as a demonstration tool and interactive laboratory experiments, which require students to construct computer molecular models and to study various aspects of their properties have been developed. Concepts in general and organic chemistry which can be taught using computer molecule modeling are discussed. The advantages of using computer molecular modeling as a vehicle for the construction of models for molecules over traditional ball and stick models are enumerated. Particular emphasis is placed on the use of computer molecular modeling as a tool for teaching the principles of polymer chemistry.

During the past two years, I had the opportunity to work on an exciting and challenging project, the **POLYED SCHOLAR PROGRAM.** In 1992 and again in 1993, I was one of five faculty members from throughout the united states, who were selected as **NATIONAL POLYED SCHOLARS.** During the first year of the program, the goals of the program were to develop curriculum materials for general chemistry courses which were designed to integrate polymer education into general chemistry. During the second year, the emphasis was changed to the development of curriculum materials to integrate the principles of polymer chemistry into organic chemistry. This project was funded by the National Science Foundation and the Polymer and Polymer Education Divisions of the American Chemical Society.

My dissatisfaction with the way chemistry has been taught in the past and my interest in computers led me to investigate the technique of computer molecular modeling as a vehicle for introducing the chemistry of polymers into general and organic chemistry curricula. A number of authors (Spain & Allen, 1990, Krieger, 1992, and Fabel, 1993) have argued that the time is right for computational chemistry to assume a significant role in the undergraduate curriculum. Others (Aduldecha, Akhter, Field, Nagle, O'Connor, & Hathaway, 1991, Jarret & Sin, 1990, Rosenfeld, 1991, and Canales, Egan, & Zimmer, 1992) have provided excellent examples of isolated molecular mechanics modeling exercises tied closely to experimental work and applications to teaching. My success in this endeavor led to the development of two sets of laboratory exercises using the molecular modeling software program, PCMODEL, during the summer of 1992 and five other exercises during the summer of 1993. These exercises were combined to produce a laboratory manual of exercises designed to teach concepts in general and organic chemistry beginning with simple molecules and progressing through the exercises to end with macromolecules.

This work has convinced me that the technique of computer molecular modeling can be very effective, not only for teaching the principles of polymer chemistry but also many of the concepts which are presently taught in general chemistry. Students should be provided with access to this exciting new technology which has provided chemists in industry with added insights into molecular

structure, structure-activity relationships, and energy correlations in molecules in both their excited and ground states. There are many concepts in both general and organic chemistry, that can be taught more effectively through the applications of computer molecular modeling than any of the methods which are presently used.

PCMODEL MOLECULAR MODELING SOFTWARE

The computer molecular modeling program used in this work, Serena Software's program PCMODEL, is an interactive molecular modeling program designed for the study of both inorganic and organic molecules. This program enables one to construct models for a large number of molecules, to display them in three dimensions, to view them from different perspectives by visually rotating the molecule, to minimize their energy, and to display the reoriented molecule in its lowest energy state. A number of molecules, such as the amino acids, carbohydrates, and nucleic acids are read directly from template files. The screen dump feature produces a hard copy of the molecule on the screen. Through the QUERY command mode, the bond lengths and distance between atoms, and angles for various bonds in the molecule may be ascertained. Bond angles can be forced to change and energies calculated and compared with the normal energy. In the energy minimization mode the total energy of the molecule is first computed and listed. Then iterative energy minimization is performed: the atomic movement (in 5-10 angstrom units) and the energy in (Kcal/mole) is listed for every 5 iterations. When the most stable conformation is reached, the structure is redrawn and the energy summary is listed.

PCMODEL can be described as user friendly and it has a short learning curve. The software is available in several versions the 3.0 version is supported by a 286 IBM compatible computer equipped with a math coprocessor or 4.0 version which requires a 386 IBM compatible computer equipped with a math coprocessor. More sophisticated versions are available for research applications but both the 3.0 and the 4.0 versions of PCMODEL are readily applicable for educational purposes and through educational discounts are readily affordable.

Both instructions for using PCMODEL as a lecture demonstration tool and interactive laboratory experiments which require students to construct computer molecular models and to study various aspects of their properties were developed.

CONCEPTS WHICH CAN BE TAUGHT

Concepts which can be taught using computer molecular modeling include:

1. Molecular structure
2. Bond lengths
3. Bond Angles
4. Hydrogen bonding
5. Geometric isomers
6. Molecular conformations
7. Stereoisomers
8. Absolute configurations
9. Molecular energies
10. Electron densities
11. PMR coupling constants
12. Polymerization

ADVANTAGES OVER CONVENTIONAL MOLECULAR MODELS

Conventional (hand-held) molecular models have (and continue to be) useful in visualizing molecular structures in three dimensions. However, construction of models for molecules through

computer molecular modeling has several advantages over the traditional ball and stick models. These include:

1. A rapid method of constructing the molecule and displaying it in three dimensions
2. Atoms can easily and quickly added or deleted
3. Nonbonded pairs of electrons are displayed
4. Bond angles and bond lengths can be obtained for the minimized molecule using the **QUERY** command and thus the molecular geometry can be predicted
5. Hydrogens which are capable of forming hydrogen bonds are labeled
6. The stereochemistry of the molecule can be determined by labeling the absolute configuration about the asymmetric carbons
7. Different conformations for a molecule can be constructed and their energies compared
8. Models for structures can be drawn, minimized, and stored. These can later be recalled to be docked with other molecules in constructing dimers, trimers, polymers, or for determining hydrogen bonding interactions between molecules
9. Pi calculations can be performed on aromatic systems to illustrate stability of pi systems as compared to conjugated double bond systems which do not have aromatic properties
10. Structures can be displayed as ball and stick, **SURF** (space filling), or electron density models.

LABORATORY EXERCISES FOR GENERAL CHEMISTRY

Three laboratory exercises have been developed for teaching general chemistry. These include molecular structures, hydrogen bonding, and coordination chemistry. The exercise on molecular structure introduces the student to the software. It is designed to teach the applications of the valence shell electron pair repulsion (VSEPR) and the valence bond theories in predicting the shapes of molecules, hybridization (bond angles, and polarity of polyatomic molecules. Students are instructed to construct Lewis structure models for molecules beginning with simple molecules which contain two atoms and progressing to three, four, five, etc., atom molecules.

Molecules are constructed as Lewis structures by first adding dots to the screen to represent atoms and then connecting the dots with lines to represent chemical bonds. All atoms start out as carbons; however, the dots are easily changed to other atoms. The energies of molecules which contain three or more atoms are minimized. During the energy minimization process, the molecules are reoriented and the bond lengths and bond angles are adjusted to fit the geometry of the molecule. Using the **QUERY** command the bond angles and bond lengths can be marked on the molecule. Using these physical characteristics, students are asked to make predictions about the hybridization and shape of the molecule. The exercise begins with simple molecules and progresses to dimers, trimers, and finally to polymers. By constructing the monomer of a polymer and saving it the computer allows the student to access the monomer and form bonds between it and other monomers on the screen. In this manner the student is introduced to the principles of polymerization early in a general chemistry course.

In the exercise on hydrogen bonding, the student is required to build both simple and macro molecules and predict whether they will form hydrogen bonds. The substructure function allows one

to identify molecules as the primary or substructure molecule and then to move them together to determine intermolecular hydrogen bonds. Models for synthetic polymer are drawn and biopolymers such as proteins and carbohydrates are readily constructed from substructure units present in the **Bio-Fragments** template. The ability of polymers to form intramolecular hydrogen bonds is tested by internally rotating the polymer molecules in three dimensions. Students are asked to make predictions about the water solubility of both the simple molecule and polymers by testing their ability to form hydrogen bonds with water.

The exercise on coordination chemistry introduces the student to the principles of coordination chemistry. Models are constructed for several ligands and these ligands are then bonded to different metals to produce several different coordination compounds. Both structural and stereochemical isomers are constructed. Students are asked to name the coordination compounds and to identify the ligand and central metal atom in each. Principles of polymer chemistry are introduced through the application of *Ziegler-Natta* catalyzed polymerizations.

LABORATORY EXERCISES FOR ORGANIC CHEMISTRY

Four laboratory exercises were developed for organic chemistry. These include organic structures, functional groups, stereochemistry, and polymer chemistry. Computer molecular modeling is especially useful in teaching line bond formulas since structural formulas begin with lines and dots and other atoms including hydrogen can easily be added or subtracted in order to readily convert back and forth between line bond formulas and expanded structural formulas. In the exercise on organic structures, students construct line bond and expanded structural formulas for organic molecules. Through rotations about single bonds, they study the energy relationships of conformations. The isoprene rule is introduced in this exercise and its relationship to properties of natural polymers is emphasized.

In the exercise on functional groups, structural units are constructed for each of the organic functional groups and stored as basic building blocks. These structural units are retrieved and incorporated with chains of carbon atoms to build the different families of organic compounds. Nomenclature of both structural units and the functional groups are introduced.

The principles of geometric and optical isomerism can be taught through the laboratory exercise on stereochemistry of organic molecules. Geometric isomerism is introduced by requiring the student to construct models for cis and trans isomers of compounds containing double bonds and ring systems. The energy relationship between geometric isomers are readily verified in the molecular energy minimization process. After constructing models for molecules containing chiral centers, the student can identify the absolute, *R or S* configuration by applying the *Cahn-Ingold-Prelog* rules for assigning priority in stereoisomers and numbering the atoms or groups of atoms about the asymmetric carbon. Molecular relationships of the stereochemistry of polymers is introduced by requiring the construction of isotactic, atactic, and syndiotactic models of the polymer 1,2-polybutadiene.

Principles of polymer chemistry which have not been introduced in the first six exercises are incorporated in one laboratory exercise, **Principles of Polymer Chemistry.** Models for monomers are constructed and stored for recall to be used in constructing polymers by either the addition or step growth polymerization mechanisms. By building models of simple and the various types of co-polymers, students learn about the structure of polymers.

These exercises were tested with a group of 12 NSF Undergraduate Research (REU) students at the University of Southern Mississippi (summer 1993) and with students in a beginning organic chemistry class at Cameron University (summer of 1993). These exercises were also used to introduce the principles of computer molecular modeling to 60 college and university faculty during the summer of 1993. Student evaluation responses indicated that computer molecular modeling is an effective

tool for teaching concepts of molecular structure. Students became excited about learning chemistry through computer molecular modeling and actually went beyond the scope of the exercises to experiment on their own. Several of the organic chemistry students indicated that this was their most positive experience thus far encountered in their study of chemistry.

My conclusions from my experiences with computer molecular modeling thus far are; not only does it offer the instructor an effective means for presenting the basic principles of molecular structure but it also provides the student the opportunity to use a sophisticated tool to study aspects of molecular structure and principles of bonding. I believe the educational benefit to the student is "EXCELLENT" and moreover the students consider learning through this technique to be fun. Chemical educators are constantly seeking better ways of teaching and the way chemistry will be taught in the future will be dictated by changes in technology. Computer molecular modeling allows both the faculty and the student to take advantage of a powerful teaching tool and how exciting it is to be involved in a true innovation in teaching.

References

Aduldecha, S., Akhter, P., Field, P., Nagle, P., O'Connor, K., and Hathaway, B.J. (1991), The Use of the Desktop Molecular Modeller Software in the Teaching of Structural Chemistry, *J. Chem. Ed.*,(68) 576-583.

Canales, C., Egan, L. and Zimmer,M.(1992), Molecular Modeling as an Inorganic Chemistry Exercise, *J. Chem. Ed.*, (69) 21-22.

Fabel, G.W.(1993), Chemistry at a Crossroads, *Today's Chemist at Work*, July/August, 20-27.

Krieger, J.H.(1992), Computer-Aided Chemistry Poised For Major Impact on the Science, *Chemical & Engineering News*, May 11, 40-56.

Rosenfeld, S.,(1991), Molecular Modeling as an Integral Part of an Advanced Lab Course, *J. Chem. Ed.*, 488-489.

Spain,J.D., and Allen,J.F., Instructional Computing as Replacement for Recitations in Freshmen Chemistry, *J. Chem. Ed.*, (67), 766-769.

Calculator Algorithms and the School Mathematics Curriculum

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Abstract: Three calculating devices are examined: the abacus, the slide rule, and the electronic hand calculator. Each device is based on an important mathematical principle. The way in which answers are determined on the calculator, however, is not obvious to the user. Calculator algorithms differ from those developed for paper-and-pencil routines. The algorithm to determine values of the tangent function is examined in detail, and inferences are drawn for the school mathematics curriculum. It is suggested that such algorithms can provide a meaningful context for the traditional curriculum.

My experience in working with prospective and practicing mathematics teachers at all levels suggests that we generally suffer from a collective lapse of memory of the long and rich history of how our present system of numeration and computation developed. In part, this is because we have tended to create mathematics curricula centred on paper-and-pencil algorithms. Moreover, we have not encouraged students to take a broader look at mathematical ideas, choosing to emphasize the episodic rather than the thematic.

In the history of computation, three calculating devices stand out; the abacus, the slide rule, and the electronic calculator. Each reflected an important mathematical principle, and each was designed around an aspect of computation difficult to carry out using earlier devices. All three are important for mathematics curricula and pedagogy. In this article, I would like to examine the relationship among three features common to each device: the mathematics underlying it, the user's understanding of that mathematics, and the accessibility of that mathematics.

The Abacus

The abacus has been used in various forms in many countries for thousands of years. The name itself is derived from the Greek work *abax* meaning "slab" and the Hebrew word *abhaq* meaning "dust," a reference to the table covered with dust on which computations were undertaken (Swetz, 1987, p. 30). We are further reminded of the earthly origins of computation when we recall that the Latin term "calculus" referred to small stones, and to calculate meant to reckon by means of moving pebbles (Davis, 1969).

The form of the abacus changed over the years, from the original dust board to the ruled table with counters placed on or between lines, to the portable frame with beads strung on wires or wooden rods. The popularity of the abacus for so many years reflected the lack of numeration systems suitable for written computation and, in particular, the absence of a zero symbol. Addition and subtraction were easy to carry out. Multiplication was more complicated, and involved repeated addition, with a number of shortcuts that the operator had to memorize. In 972 AD, Gerbert devised a method for division, but it was not widely adopted.

Around 1100 AD, the Hindu-Arabic system of numerical notation filtered into Western Europe. This led to a long, sometimes acrimonious debate between the *abacists* who used the abacus, Roman notation, and duodecimal fractions, and the *algorists* who advocated Hindu-Arabic notation, symbolic computational algorithms, and decimal fractions. Generally, the Italian merchants championed the new system, while the Germans, in their "counting houses," favored the abacus.

The major mathematical element underlying the operation of the abacus was an implicit place value system. Wilder (1968) points out that a major deficiency of the abacus was the lack of a recording element; the slate had to be wiped clean, as it were, for each computation to take place. The empty wire required that an operational symbol be developed to represent that condition. If so, this is a case where the technology spurred the development of symbolic and conceptual advances.

The Slide Rule

In 1614, John Napier published his "Description of the Wonderful Law of Logarithms." The result was a giant leap in computing power, with particular application to the needs of astronomy. Shortly thereafter, Edmund Gunter constructed a logarithmic scale and used a pair of dividers to add lengths, thereby multiplying the numbers. William Oughtred extended this idea, first by developing his "circles of proportion" which consisted of eight fixed circles and two movable pointers radiating from the center (see Park, 1969 for an illustration). This device allowed one to determine the sine and tangent of angles and to multiply and divide integers. Later he invented the rectilinear slide rule, consisting of two logarithmically calibrated rulers that slid next to each other. Over a hundred years later, in 1775, John Robertson added a central runner, and the slide rule as we know it was complete.

The slide rule operated on a well-known theoretical principle (addition of logarithms) and it made effective use the place-value, base-ten, Hindu-Arabic numerals. Not only did the slide rule allow one to multiply and divide, it also made it possible to determine square roots and cube roots and to perform computations using exponential, logarithmic, and trigonometric functions. Moreover, in contrast to the abacus, its operation was transparent to the user. Of course, one might develop facility with the slide rule (using, one might say, a physical algorithm) without understanding the principles on which it was based, but those principles were clearly evident in the way the instrument was constructed and operated.

The Electronic Calculator

As technology developed during the industrial revolution, a number of a people attempted to create a calculating machine. Pascal actually built a computing machine that used gears to handle addition; other machines, most notably Babbage's "analytical engine" never got past the prototype stage. The next great step in computing power occurred only in the mid-20th century with the development of computers and later, electronic hand calculators.

Let us now consider the features of this computing device. Some keys, when depressed, generate numerals in the display, others perform operations, while still others have special functions such as storing results in memory or clearing errors. All students in our schools have access to these machines and are, or soon will be, encouraged to used them whenever appropriate. Students will be taught how to depress the keys, how to generate an answer, and how to record the answer using the appropriate number of significant digits. In other words, students will develop efficient physical algorithms to operate a calculator, much as the Romans did an abacus. They will, however, use Hindu-Arabic numerals to record their results rather than Roman numerals.

But suppose a student says, "How does this device work?" The mathematical procedures to obtain answers are not manifest, as they are for the abacus and the slide rule. They are, nonetheless, based on principles that are extremely important in our electronic age. The main mathematical idea is that of place value, using not base ten as for the abacus or slide rule, but base two. At one time, in the 1960s and 1970s, the topic of different bases for place-value systems was very popular in the school mathematics curriculum. But no longer. Nor is it mentioned specifically in the Standards document (NCTM, 1989). One can only speculate as to the reason for the demise of the study of different bases, but it seems odd that we should deliberately remove from the school curriculum a topic fundamental to understanding the operation of calculators and computers.

The study of different bases need not be difficult or complex. At the primary level, children should experience grouping objects into equal piles and attaching number names to the result. The counting games in Baratta-Lorton (1976, Chapter 11), for example, constitute an excellent introduction to patterns with groupings smaller than ten. They provide a strong background for children to understand the base ten place value system. At the intermediate level, students can be introduced to operations on numbers in different bases using counters and paper cups (see, for example, Baratta-Lorton, 1977, Chap. 8). Having developed a solid conceptual understanding of the base ten system through experiences with different bases, junior secondary school students should now be in a position to undertake a more formal study of the binary system. This might be done in conjunction with a project to explore how a calculator does its thing...a natural connection between mathematics and technology. In the senior grades, students might also be asked to investigate number bases available on some scientific calculators. My old Casio fx7000G, for example, includes conversions among binary, octal, decimal, and hexadecimal representations. As a minimum, students should understand the binary representation of numbers, the operation of addition, and the modelling of these using off-on switches. They should not be

expected to give a detailed description of the internal operation of the calculator, but their school experience should equip them with the basic ideas of electronic computation.

Calculator Algorithms

At the senior secondary level, other mathematical issues arise, particularly the means by which the calculator determines the values of scientific functions. For example, how does the calculator determine the value of a trigonometric function, say sine 25°? Does it compute the value of the side opposite over the hypotenuse? Does it have a table of values stored inside it that it can consult? If so, does it interpolate to find intermediate values for angles measured in minutes or seconds?

Several years ago, I asked a number of secondary mathematics teachers as well as colleagues in our Faculty of Education and the Mathematics Department how the calculator determines values of trigonometric functions. No one was really sure, not even two people whose specialty was numerical methods. The most frequent suggestion was that some form of power series was used for the trigonometric, exponential, and logarithmic functions, and that Newton's method was used for square roots. At that point, I decided to pursue the matter through the technical support service of calculator manufacturers. My inquiries from the first manufacturer led to the information that the process involved the "cordic" (coordinate rotational digital computer) system. When I asked for details, I was informed that what I wanted was proprietary information which would not be divulged. A second manufacturer, however, was fully cooperative and supplied details of all the algorithms they used for the common scientific functions.

I was delighted to find that all my colleagues had been wrong. It turned out that trigonometric functions are determined strictly using trigonometric means. The calculator really does compute the tangent function as the ratio of the side opposite over the side adjacent, using an iterative procedure to determine the lengths of the two sides. That procedure is worth looking at in detail, in order to assess whether it would be understandable by secondary students. The description that follows is based entirely on Egbert (1977).

The values of all functions are derived from the tangent function. Sin ø is determined from the formula $\sin \varnothing = \dfrac{\pm \tan \varnothing}{\sqrt{1 + \tan^2 \varnothing}}$ and cos ø is determined from $\cos \varnothing = \dfrac{\pm \cot \varnothing}{\sqrt{1 + \cot^2 \varnothing}}$.

The key to computing the tangent function is that "the tangent of a large angle can be found by manipulating smaller angles whose sum equals the large one (Egbert, 1977, p. 18)." First the angle is converted to radians and rescaled by repeated subtraction of 2π to an equivalent value between 0 and 2π.

Now, suppose we have a vector T whose angle of rotation and X and Y components are known, say $\varnothing_1$, X_1, Y_1, as shown in Figure 1. Suppose the vector is rotated through an angle $\varnothing_2$, yielding components X_2 and Y_2. The tangent of angle $(\varnothing_1 + \varnothing_2)$ is the ratio Y_2/X_2 for any value from 0 to 2π.

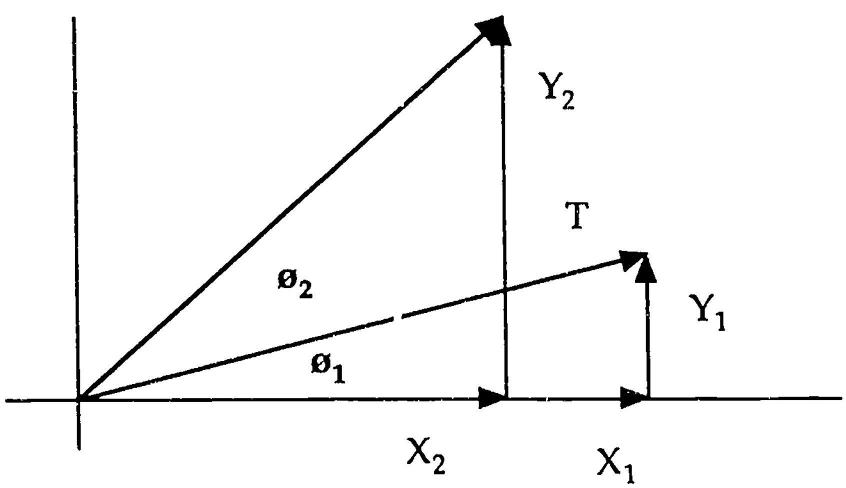

Figure 1. Initial and final positions of rotated vector

We can determine values of Y_2 and X_2 from the known values of ϕ_2, X_1, and Y_1 as follows:

$$
\begin{aligned}
Y_2 &= T \sin(\phi_1 + \phi_2) \\
&= (Y_1/\sin \phi_1)(\sin \phi_1 \cos \phi_2 + \cos \phi_1 \sin \phi_2) \\
&= Y_1 \cos \phi_2 + Y_1 \cot \phi_1 \sin \phi_2 \\
&= Y_1 \cos \phi_2 + X_1 \sin \phi_2
\end{aligned}
$$

Similarly,

$$X_2 = X_1 \cos \phi_2 - Y_1 \sin \phi_2$$

To put these values into a form amenable to the calculator algorithm, we divide each side of each equation by $\cos \phi_2$ to obtain:

$$
\begin{aligned}
Y_2/\cos \phi_2 &= Y_1 + X_1 \tan \phi_2 \quad (= Y_2^*) \qquad (1) \\
X_2/\cos \phi_2 &= X_1 - Y_1 \tan \phi_2 \quad (= X_2^*)
\end{aligned}
$$

Now the ratio of Y_2^* to X_2^* is equal to the ratio of Y_2 to X_2, and hence is equal to the value of the tangent of $\phi_1 + \phi_2$. If we know the components of an initial vector, and are given an angle of rotation we can calculate the components of the rotated vector and hence the tangent of the total angle of rotation. That is, to calculate any tangent we need a known initial vector, let's call it a "seed", and we can work our way up to the required angle in steps. The trick in the calculator algorithm is to find that seed and to decide on what steps are convenient.

Let's take the steps first. The easiest approach is to define each step by setting up $\tan \phi_2$ as a power of ten. In this way, for example, one step might be $Y_2^* = Y_1 + X_1(0.01)$. Using degrees for simplicity, we know that the tangent of 45^o is 1. The tangent of 5.7105932^o is approximately 0.1, and for purposes of illustration let's call it 5.7^o. The tangent of 0.57^o is approximately 0.01; and so on. So what we have to do is break down the original angle into multiples of 45^o, 5.7^o, 0.57^o, and so on to the desired number of decimal places of accuracy, leaving a final remainder, R, which becomes the seed. That is,

$$\phi = n_0(45) + n_1(5.7) + n_2(0.57) + n_3(0.057) + \ldots + R \qquad (2)$$

where $n_0, n_1, n_2, \ldots$ are determined by successive subtraction of angles 45, 5.7, 0.57, ...

Now to work our way back from the seed R we need initial values for the X and Y components of R. To retain the desired calculator accuracy, R must be very small, less than 0.001^o, and for such small angles, in radians, $\sin R = R$ and $\cos R = 1$. So the seed components X_1 and Y_1 become 1 and R. Now equations (1) can be applied to calculate the components of the seed augmented by one of the smallest steps. That result in turn becomes the starting point for another application of equations (1). The number of times equations (1) are applied is equal to the number of steps, $n_0 + n_1 + n_2 + \ldots$, identified in (2). The final result is the value of $\tan \phi$.

So it turns out that the best guesses of my colleagues were wrong. Behind the machine lie surprises for those of us trained in traditional ways. To a considerable extent, we use the calculator as our ancestors used the abacus, efficiently and accurately, but generally unaware of the underlying powerful mathematical ideas.

Conclusions

Each calculating device described here has a physical algorithm that will yield a desired result, and each of these is based on a mathematical algorithm. For the abacus and slide rule, students can identify the mathematical algorithms based on the physical operations. In the case of the calculator, the mathematical algorithms are not readily accessible.

One of the aims of our school mathematics program should be to produce students who have some appreciation for the long human struggle to develop computational power. We need to consider seriously reconstructing our mathematics curriculum along the lines of what Bishop (1988) calls "mathematical enculturation." The abacus has a natural place in the elementary curriculum; the slide rule, until recently, was part of the study of logarithms in the secondary curriculum. In the case of the calculator, however, we seem to have moved away from the study of number bases and avoided the issue of calculator algorithms entirely.

The calculator algorithm described in this article demonstrates how important such a topic can be. It neatly demonstrates the principle of recursion, one of the most important concepts in modern mathematical fields of study such as artificial intelligence and chaos theory. On the other hand, the mathematical knowledge needed to understand the algorithm is well within the bounds of the traditional trigonometry curriculum in the secondary school. But, what it does in addition, is to integrate and unify the trigonometric topics usually studied. The trigonometry involved consists, at least, of converting degrees to radians, reducing an angle to standard form,

vector rotation, applying trigonometric identities, and calculating inverse trigonometric functions. The topic would be eminently suitable for group investigation or classroom discussion.

In the past, arguments for curriculum change have emphasized how using calculators will affect what, and how, mathematics should be taught. Generally, we have seen moves to reduce paper-and-pencil computation and to create more realistic problems. Until now, however, the traditional mathematics content has remained. It is heartening to read in the Standards (1989) that

> The development and analysis of algorithms lie at the heart of computer methods of solving problems. Thus, a consistent effort should be made throughout the 9-12 curriculum to provide opportunities for students to construct mathematics from an algorithmic point of view. (p. 178)

Calculator algorithms should form a important element in the study of discrete mathematics in the secondary school. It will be ironic, indeed, if the electronic calculator spawns a new generation of abacists who do not understand the language and procedures of the modern algorists.

References

Baratta-Lorton, M. (1976). *Mathematics Their Way*. Menlo Park, CA: Addison-Wesley.

Baratta-Lorton, R. (1977) *Mathematics...A Way of Thinking*. Menlo Park, CA: Addison-Wesley.

Bishop, A. (1988). *Mathematical Enculturation: A Cultural Perspective on Mathematics Education*. Dordrecht: Kluwer.

Davis, H. T. (1969). The history of computation. In *Historical Topics for the Mathematics Classroom*, 1969 Yearbook of the National Council of Teachers of Mathematics, pp. 87-117. Washington, DC: NCTM.

Egbert, W. E. (1977). Personal calculator algorithms II: Trigonometric functions. *Hewlett-Packard Journal*, *28*(10), 17-20. (Obtained from Hewlett-Packard, Corvallis Division, Calculator Support, 1000 N.E. Circle Blvd., Corvallis, OR 97330)

National Council of Teachers of Mathematics. (1989). *Curriculum and Evaluation Standards for School Mathematics*. Reston, VA: NCTM.

Park, R. M. (1969). Oughtred and the slide rule. In *Historical Topics for the Mathematics Classroom*, 1969 Yearbook of the National Council of Teachers of Mathematics, pp. 271-273. Washington, DC: NCTM.

Swetz, F. J. (1987). *Capitalism & Arithmetic: The New Math of the 15th Century*. LaSalle, IL: Open Court.

Wilder, R. L. (1968). *Evolution of Mathematical Concepts*. New York: Wiley.

Cyberspace and the Classroom: Electronic Resources as Instructional Aids

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Abstract: The Internet and its resources that are available to teachers and students are surveyed. These resources are discussed from a social/philosophical perspective of issues related to science education. The issues are derived from a commentary by Paul DeHart Hurd concerning science education research and include democratization, modernization and futurization of the curriculum, contextualization for real-life and learning to learn for lifelong retention. The Internet provides an environment highly conducive to meeting these goals, as well as integrating an important new technology and skill seamlessly into the curriculum.

Science and mathematics education continue to face many challenges. Our world is becoming more complex and technical with increasing amounts of material to be taught. At the same time many schools are facing decreased resources and support. Headlines in newspapers read "Report Urges Science Teaching Overhaul," or "American Schools Shortchange Students in Science, Study Reveals." Teachers are continuing to be put in a situation to teach more, better and faster with less in a highly critical environment.

At the same time there is a revolution in electronic resources and access. This is the result of the growth of the Internet and similar computer networks. The Internet can be neglected in the science and mathematics curriculum, viewed as an additional topic to be covered, or made an integral part of the study and practice of science and mathematics. This paper will attempt to look at the use of electronic resources to meet the challenges of science and mathematics education from a particular philosophical perspective culled from a commentary by Paul DeHart Hurd. After an introduction to cyberspace, different types of resources are detailed. These are then critiqued in the light of the comments made by Hurd.

Science and technology are advancing at an astonishing rate. If we were to view the evolution of computers from the large ENIAC, EDVAC and UNIVAC systems of the 1940's and 1950's to the computing capabilities of the modern desktop and portable computers, it would be a rapid growth rate, equalled by few other technologies. One of the goals of education must be to teach students not just to learn the skills needed for today, but to learn to adapt to the new technologies and challenges which come at increasing speeds. To do less is to do the student a disservice.

No one can predict where the electronic world is going. It may be true that the only constant is change. The electronic world is changing at a rapid speed, but more importantly, in a manner that makes prediction difficult. The term used to describe the computer environment and the people around it, "cyberspace" is thought to have started in 1984 in the book *Neuromancer* by William Gibson. In the past ten years it has become widely-used in the common vocabulary. Cyberspace has even become a subject heading in the ERIC education database.

If we can't predict what will happen, one thing we can agree on is the rapid increase in the number of computers and resources available . The resources are increasing in quantity, quality and types. While early resources in weather may have included a few discussion groups and daily weather forecasts, current resources include frequent updates and video weather maps. With the proper equipment, audio and graphic information can be utilized. Schematics, pictures and photographs are now online. The resources are literally increasing daily.

The number of ways to access the Internet has also increased greatly. Only a few years ago Internet access was through institutions that had invested the capital and expertise to become an Internet site. Today almost anyone can subscribe to a commercial provider and have as least some Internet access in the home, office or classroom for substantially less than one dollar per day. Since these services provide a myriad of resources, their benefits to educators are waiting to be mined.

Major sources of electronic resources for educators are available through the Internet. While the technical definition of the Internet is those computer networks that use TCP/IP (transmission control protocol/Internet protocol), it is commonly viewed as thousands of small and large computer networks which can communicate with each other, or are internetworked. Many systems that are not actually part of the Internet can communicate with the Internet through gateway systems among the networks.

The Internet started as the ARPANET in the late 1960's, a network to link the researchers of the Defense Advanced Research Projects Agency of the US government. It expanded to universities, colleges, schools, corporations, commercial organizations, non-profit groups, and almost any type of organization imaginable. The Internet now numbers thousands of sites and approximately two million computers around the world.

The Internet accessible resources can be divided into several major groups. First and most basic is electronic mail or e-mail. Electronic mail is a messaging service which allows individuals with Internet access and electronic mail addresses to send messages around the world in relatively real-time situations. Communication becomes fast, easy and efficient. Most systems offer e-mail accounts. E-mail offers many opportunities for teachers and students to correspond directly with other students, teachers and researchers on a topic of interest. Biology classes that are analyzing stream water could coordinate research with classes at schools upstream and downstream, share data and discuss results for a more interesting and comprehensive study than one done with local data only. Air pollution could be studied internationally. The possibilities are almost limitless.

List services or discussion groups are related to e-mail. These are groups of individuals with common interests who have registered to read and send messages from and to other members of the discussion group. Discussion groups cover a wide range of topics and there are many interesting ones in the sciences, mathematics and education. Weather, chemistry, biology and math discussion groups are common and provide an interested and very knowledgeable group of individuals. Students can pose or answer questions on the group or simply monitor discussion.

Newsgroups are also subject specific lists. Instead of arriving in your electronic mailbox like e-mail or discussion groups, newsgroups are housed on a mainframe computer. They are accessed by logging into the system and reading the messages that are there. These are also very subject-oriented and range from the truly pertinent to the ridiculous. Newsgroups can be as focused as sci.physics.research which is a moderated discussion of current physics research, or rec.arts.startrek.tech which discusses the technology of the Trek universe.

Databases are a very pertinent source in the sciences. Many databases in a variety of subjects are mounted on computers around the world and are open to individuals with Internet access. Government resources, including several from NASA, are available as well as some from universities and professional organizations. Information in genetics, oceanography, space and astronomy is available through the Internet for use in class or laboratory. These can be located almost anywhere. Access can be direct if the specific computer address is known, or through one of the navigators discussed below.

Software, datasets and other large files that can be useful are mounted on different mainframes and available for free borrowing, or downloading. The process to retrieve these is file transfer protocol or ftp. It allows an individual to dial into a remote computer and request that the material be sent to their home computer. The copy is then available for their use. Archie, a service that tracks free software on the Internet, can be used to locate packages that may be useful in the classroom.

With the myriad of sources listed above reliable, easy access is essential. Since the Internet is relatively new and growing so rapidly, it may be of little surprise that consistently reliable, easy access has not yet arrived. However, navigators are readily available and are becoming more reliable and can assist the Internet traveler. These include hypertext based guidance through the Internet in WAIS, WWW (World Wide Web) and Mosaic, and menu driven systems like Gopher and LIBS. These navigators attempt to find Internet resources based on keywords or subject divisions. Just as the Internet is growing, these navigators are increasing in both number and relative ease of use. Excellent books on the Internet and Internet accessible resources also can guide both the teacher and their student through the "cyberjungle."

With the increasing complexity of the systems and the multiple ways to navigate the Internet, the teacher may question whether the initial effort is worth the result. It can be argued that the social and education benefits are so great and long lasting that the rewards far outweigh the effort. An argument also can be made that the new computer generation that is going through the schools now already know how to find MUDs (multiple user dimension or role playing games), song lyrics archives and cyberpunk discussion groups. Teachers need to direct them to some electronic educational tools, let them see the benefits and then stand back and let them explore.

Paul DeHart Hurd (1993) notes that science education is demanding qualitative reasoning skills which must have a strong interdisciplinary nature. Research in science education must move beyond empirical models to "social analysis and normative interpretation." His paper looks at the need for reform in science education research and lists several issues that science education research should consider. A strong argument can be made that these same issues for science education reform also provide a very solid basis for considering the modern science curriculum and the addition of electronic applications. These issues may be paraphrased to include:

1. Democratization of science education to effect responsible citizenship.
2. Futurizing science courses with the goal of "learning to learn".
3. Contextualizing the science curriculum in terms of real-life and real-world affairs.
4. Modernizing science courses by selecting subject matter from contemporary research fields.
5. Learning in science should strive to assure lifelong retention.
6. Proactive connection of theory with practice in demonstrable ways.

A strong argument for the Internet use in the classroom is based on these six points. There is a philosophical aspect to the Internet and its resources that can be overlooked in its utilization. In an attempt to see the trees - the types and quantity of resources - the forest - or the real framework of the system can be missed. By its current operation, the Internet is socio-economically and demographically blind. In the event that a school cannot get an easy, direct connection to the Internet, many commercial vendors can provide relatively affordable access. Of course, there is the future Information Highway, which will probably provide this access. For this reason, the Internet may be one of the most democratic resources available to teachers; democratic in the sense of both access to and the use of it without regard to social, economic, racial or geographic parameters.

The second phrase in point one is "to effect responsible citizenship." Responsible citizenship depends on many factors, access to information has to be considered a cornerstone. Again, the Internet provides that to both students and educators. It provides that information without going to the library, without concern for local resources and in a fast and efficient manner.

Point two concerns "futurizing" and "learning to learn." The probable shape of the future is here in the Internet. While we can hope that it will become easier to operate it has already provided us with a quantum leap into the future. Real time communication around the world, transfer of files, software and data at one's fingertips were the stuff of science fiction and now are the activities of school students.

On the other hand, the Internet is a classic case of rapid change and the need to develop a conceptual framework upon which to build Internet knowledge. The Internet changes and grows daily and the resource guides are always behind. Lifelong learning, exploration, trial and error, and the search for patterns; skills we try to instill in our science students are necessary on the Internet. Students and teachers cannot become complacent on the Internet. A new source or new navigator may provide better access, so learning should be continual.

Contextualizing the curriculum into real life is a natural feature of the Internet. Students can access documents or data on an issue they study; discuss their findings on lists or directly with researchers; develop and propose problems, methods or solutions and garner the advice of others. They can keep up to the minute on new scientific findings and news releases. Resources, especially newsgroups represent interdisciplinary aspects of subjects. Students can search for the person, database or other resource that is focused on the application of a classroom activity. The Internet provides access. Schools may refuse to support the cost of a telephone call to students in Iceland to discuss geothermal energy, time constraints may not support postal communication, but the Internet provides both cost and time benefits.

Related to the earlier aspect of lifelong learning is learning to understand. Rote memorization of detailed processes is not the goal here. With emphasis on the words "understand" with "lifelong retention" the goal necessitates continual learning beyond rote. Students can continue to search for new information, opinions,

and if we do our job correctly, critically evaluate the information. After evaluation they can incorporate this information within their knowledge base and continue to grow. Several "ifs" must be considered here. If the number of people who accept the paranormal are stated correctly, science and mathematics education has a monumental task facing it now and in the future. If the populace is going to need to make increasingly complex decisions concerning science and technology issues, then information will continue to be more critical. If the Internet is going to pervade our lives then teaching it as a resource becomes critical. But, if the instruction is done, educators have provided future adults the means to continually address their own information needs.

Last, Hart requests that science teaching be more proactive, connecting theory with practice. It may be bold enough to say here that the use of the Internet may be proactive enough to connect technology with practice and let the theory catch up with us. Students are ripe for computer resources. Many operate video games, software and keyboards as if they were natural appendages. Rather than wait for long studies to show that students can access more materials faster, manipulate them better, relate and enjoy the resources, activities and teaching aids on the Internet; instructors can grab the electronic future now and experiment with its applications and possibilities. Experimentation, trial and error, and new explorations are the basis of science. Students and teachers exploring and utilizing the resources of the Internet, not in place of the rest of the educational experience but as an integral part of the curriculum, will be prepared for the electronic future that is already here.

Hurd, P.D. (1993) Comment on science education research: A crisis of confidence. *Journal of Research in Science Teaching*, 30 (8), 1009-1011.

The Spreadsheet as a Learning Tool in the Science Classroom

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Abstract: The use of commercially available spreadsheet programs has been used successfully to develop critical thinking skills in the science classroom. The most direct benefit is the time saved in graphing and repetitive calculations. This time can be used to further explore the nature of the experimental findings or to start new material. Macro functions and interactive dialogue boxes can be made to aid novice users through the software. Graphical analysis is rapid and the visual display of the data is insightful to the students. The built in functions for regression and statistical analysis aid in this approach. The auto-recalculation feature allows the student to see the effects that modifying value in a calculation has on the final result. This idea is used to demonstrate how the magnitude and precision of experimental data impacts the calculated answers. This analysis then extends to rational experimental evaluation and redesign.

The current theme in science education is returning to the concept of science by inquiry. So, how can we best utilize the available technology, specifically the use of computers, toward achieving this goal? Certainly computer data acquisition, computer simulations, and interactive programs for drill work are important and are actively taken advantage of in our classrooms. However, we are also interested in developing computer skills and critical thinking skills. One successful approach is to integrate the work up of experimental data using commercially available and well documented spreadsheet programs. The balance of this manuscript addresses the built in features of spreadsheet programs which are useful in creating spreadsheet applications and the utility of incorporating spreadsheet programs into the lesson.

Features of Spreadsheets

Spreadsheet have many features which are particularly useful in creating applications for student use. First of all, these programs come with an array of arithmetic functions that rapidly perform repetitive calculations such as sums, averages, standard deviations, linear regression and matrix calculations. In addition, the creator of the spreadsheet program can "lock" certain cells, preventing the novice user from altering the values or calculations associated with these cells. This protects your program from accidental destruction. The programmer can also highlight regions within the spreadsheet to direct students attention for data entry and results location. Spreadsheets also have an auto-calculation function that continually updates the entire spreadsheet as the contents of any cell is altered. This is an important feature when you want the students to watch the effect of changing certain variables in

a calculation. This update also extends to an embedded graphics as well. The programmer can also create macro buttons within the spreadsheet. Each button when selected carries out a series of prerecorded commands. These are very useful for multi-step operations and allow the creator of the spreadsheet to develop "turn key" methods for file storage and retrieval, output and graphics display. These buttons can also be used to create pop up dialogues to interact and instruct the student through the program. There is a set of logical functions which allow the programmer to create interactive drills where the student can compare their calculated values against those calculated by the spreadsheet. Commercial spreadsheet programs like Lotus 123[1], Quattro Pro[2], and Excel[3] are well documented, well supported and have excellent on-line help making them relatively easy to use. These programs are remarkably similar so, when you learn one you have skill using any of them.

Advantages of Spreadsheets

The most direct advantage of spreadsheets is in reducing the amount of time spent graphing, doing repetitive or simple calculations. Secondary science students already competent at graphing data pairs and doing so takes time which could be better spent on analysis of the resulting graphs. Spreadsheets possess utilities for the rapid presentation of graphs and the generation of hard copy. This is an important feature because students are now able to view their experimental data before leaving the lab. In the event of a "suspicious" data point, the student can rapidly check for transcription errors or opt to retake the data. This tends to reduce the confusion that results from trying to interpret the erroneous data set and gives them more confidence that science really works and can be done by all! In addition, calculations like sums, averages and standard deviations are also rapidly generated, leaving the student more time to reflect on the implications of the results instead of generating the numbers.

For example, in the analysis of the simple pendulum, students measure the period of a pendulum as the length of the pendulum is varied. The student discover that a plot of the period versus the square root of the length is linear. The slope of this line is obtained using the regression analysis function. The acceleration due to gravity, g, is obtained from the slope. The students are asked to compare the value obtained from the slope and the values obtained from a point by point analysis. Typical data shows the % error in the measured value of g increases as the string get shorter or as the mass gets lighter. This opens a discussion of the limits of the simple pendulum. From this exercise they discover that there is value in plotting the experimental data beside determination of the mathematical relationship.

To increase the precision in measuring the period of the pendulum, the students measure the time required for 20 swings of the pendulum. At times the students will lose count and measure the time for 19 or 21 swings. This mistake is readily seen in the plot of the data. Having been able to detect the error before leaving the lab, they are able to go back and validate the data. This is an important benefit of having the data workup and presentation accelerated as frequently errors are only discovered during the analysis of the data.

Graphical Analysis

Another asset in the use of spreadsheets is in graphical analysis. The raw experimental data can be manipulated and displayed in several functional forms. The students enter their data into a single column and the program can then display the data in a variety of functional forms. This allows the student to determine the mathematical relationships between the variables by graphical analysis. The student scrolls through plots of various functional combinations of the variables looking for the linear relationship. Spreadsheets also have resident regression analysis routines to calculate the slope, the intercept, precision, and correlation coefficients. Many of the spreadsheets are also capable of performing higher order fitting and smoothing of the data.

One method for the kinetic analysis of a chemical reaction is graphical. The order of a reaction with respect to a reactant is determined by measuring the changing concentration of the reactant of interest over time, while the concentrations of the other constituents are kept constant. This is practically done by keeping the concentration of the other constituents high with the respect to the reactant under study. Armed with this data the experimenter then prepares a series of plots. The [X] vs time, ln[X] vs time, and 1/[X] vs time, where [X] is the concentration of reactant of interest. If the reaction is zeroth order with respect to X, then the plot of [X] vs time is linear, the slope being the rate constant. If the reaction is first order in X, then the plot of ln[X] is linear, and the slope is the negative rate constant. If the reaction is second order, a plot of 1/[X] vs time is linear and the slope is the rate constant. For this experiment, the student enters in data and the spreadsheet automatically displays each of the three plots. The student then inspects the graphs, determines the reaction order and then uses the regression function to determine the experimental rate constant. To generate these plots manually takes considerable time and for students well versed in graphing, this is a tedious task. The spreadsheet enables rapid analysis leaving time to study all of the chemical constituents in the chemical reaction, not just one which is typical given the time constraints. Now the class can explore such topics as pseudo-first order reactions and mechanisms.

Flexibility

The spreadsheet is readily and effectively used with other programs. Computer data acquisition with an interface board[4-6] can be imported into spreadsheet. Most all programs are capable of storing the data in an ASCII format. Spreadsheets have built in features to directly import and sort ASCII files in common formats and also have the flexibility to parse the nonstandard formats. For example, using a computer simulation of the Rutherford experiment[7], students examine the scatter of alpha particles over a wide range of angles while varying the atomic number of the target, the thickness of the foil, the energy of the alpha particle and the impact parameter. The program visually shows the effects of the of changing these parameters. However, by importing this data into the spreadsheet, a more detailed analysis can be done. The benefits are two fold. If the software for the interface or the program doesn't have the type of analysis you want to perform built in, then importing the data allows you this flexibility. In addition, consistent use of the spreadsheet as the analysis tool means the need for you and the students to learn the details of several different software packages is eliminated.

Critical Thinking Skills

A key critical thinking skill to develop in students is how to evaluate the impact that the magnitude and precision of measured parameters has on the calculated result. Manipulating the values and seeing the effect this has on the final result allows them to gauge the consequences of the variation in the measured parameters. This technique points out limitations in the current methodology and allows a thoughtful analysis of the experimental design and how it might be altered to improve the results.

The auto-recalculation feature of the spreadsheet re-evaluates the calculated results when the content of a cell in the spreadsheet is altered. An example exploring the effect that the magnitude of variable can have of the outcome of experiments is analyzing the effect the concentration of the reactants in a acid/base titration has on the determination of the endpoint. A plot of the pH versus the volume of titrant delivered and the derivative plot are displayed on the same graph. Starting from fairly concentrated solution of the acid and the base, the students observe that the sharpness of the endpoint decreases as the concentration of the reactants is reduced. From these observations they draw conclusions about practical limits to a titration and why titration of dilute systems such as acid rain or seawater is not a trivial task if high precision is desired.

This concept can also be used to demonstrate how the precision of the variables involved effects the results. The students alter their data an amount commensurate with the precision of that measured value. By examining the results using a range of values the student can determine which parameters limits the precision of the final result. The students are now challenged to consider rational approaches to optimal experimental redesign.

For example, Charles law, the dependence of the volume of a gas sample with temperature at a constant pressure, can be performed in a simple manner. A drop of a colored liquid is placed in the stem of a disposable plastic pipette trapping a sample of air in the bulb. The pipet is exposed to different temperatures and the volume measured. The volume is measured by summing the volume of the bulb and the volume the gas occupies in the stem. The volume of the bulb is measured by filling just the bulb up with the liquid and determining the volume with a graduated cylinder. The volume in the stem is determined by measuring the length of the stem that the gas occupies and calculating the volume assuming the volume to be a cylinder. All together this requires four measurements; the temperature, the volume of the bulb, the length of the stem and the radius of the stem. A plot of the volume versus the temperature in Celsius yields a linear plot with an x intercept indicating absolute zero. The students can then manipulate the values for the temperature, the volume of the bulb, the length and the radius to see which factor with its estimated precision, most effects the value of absolute zero. It turns out that precision in measuring the length using a mm rule has considerable impact of the experimental value of absolute zero. Thus the students conclude that increasing the precision of this measurement is a high priority in the experimental redesign. Some students opt for a better ruler, some suggest a larger temperature range to increase the distance traveled, and eventually the better students will choose to use a pipet with a narrower bore to increase the distance

traveled by the drop.

Conclusions

Without the use of spreadsheets this type of analysis discussed in this manuscript are difficult to do without spending a great deal of time on one subject or experiment. We have had great success using spreadsheets in our classrooms as a means to relieve students from tedious and repetitive tasks, free up time to cover other content areas and as an tool in the critical analysis of experimental data. Perhaps spreadsheets sound intimidating, however, current commercial spreadsheet programs like Lotus 123, Quattro Pro and Excel are well documented, well supported, and have excellent on-line help menus that make them relatively easy to use. The mathematical syntax used by these programs is similar to that used by the graphing calculators. Options and commands are accessible through pull down menus. These programs are remarkably similar, so that when you learn one, you have skill using any of them. Work up of experimental data using spreadsheets also provides the students with important computer skills and if used at large eliminates the need to master all aspects of scientific software. There is also a wealth of spreadsheet applications out there to be incorporated into the science classroom.[8]

References

1. Lotus 123, Registered Trademark, Lotus Development Corporation.
2. Quattro Pro, Registered Trademark, Borland International Inc., Scotts Valley Ca.
3. Excel, Registered Trademark, Microsoft Corporation, Redmond, Wa.
4. Pasco Scientific, Roseville, CA.
5. Keithley Instrument Inc., Taunton, Ma.
6. Vernier Instruments, Portland, Ore.
7. JCE Software, American Chemical Society, 1993. Note: JCE software is an excellent source of spreadsheet and spreadsheet compatible programs.
8. Parker, O.J., and Breneman, <u>Spreadsheet Chemistry</u>, Prentice Hall Englewood Cliffs, New Jersey. 1991

Assessing and Contrasting Formal and Informal/Experiential Understandings of Trajectories

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Abstract: Do people necessarily predict a projectile's motion most accurately when they use appropriate, Newtonian (i.e., curvilinear or vertical) trajectory forms? The present analysis tests this "Joe Montana hypothesis" by contrasting the accuracies of pendular-release trajectories as predicted by subjects using either these "correct" paths or non-Newtonian (e.g., diagonal) paths. Both correlations and Euclidean deviations are employed as measures. Results include the findings that, while Newtonian responses *generally* yield higher accuracies than other responses, in a minority of cases, subjects can achieve superior accuracy by employing some of three aspects of impetus in their trajectory forms (e.g., dissipation, internal force, and curvilinear impetus). Further, the data reveal that women may fare better in naive physics comparisons when more ecological (and less formal) measures of accuracy are employed.

This study focuses on the degree to which differentially rich understandings of Newtonian physics functionally affect students' performance on tasks that involve the prediction of kinematic trajectories. Researchers in the field of Cognition and Instruction tacitly assume that students who have a more correct formal understanding of the physics of motion (say, regarding the "form" of trajectories) will also have a better sense of the *phenomena* of motion, for instance, than laypeople who have merely interacted with moving objects. This need not be the case, however, since relatively untutored individuals can obviously gain considerable kinesthetic facility with such objects. This possibility is what might be referred to (perhaps a bit facetiously) as the "Joe Montana hypothesis"—the suggestion that there is a sense in which the famous (American) football player, Joe Montana, is a "better physicist" than was Albert Einstein, particularly regarding his ability to accurately and quickly predict a projectile's position. (I.e., the "correct" may not necessarily coincide with the most "accurate.")

To empirically contrast these views, predictions about pendulum-bobs that break free from their supporting strings at various swing positions are analyzed (cf. Caramazza, McCloskey, & Green, 1981; Ranney, 1987/1988, 1988, in press; Ranney, Schank, Mosmann, & Montoya, 1993; Ranney & Thagard, 1988; Schank & Ranney, 1992). In this way, the formal properties (e.g., parabolic vs. diagonal, etc.; see Ranney, in press) of such trajectory predictions can be compared with the accuracy of these predictions (e.g., how far they deviate from the veridical trajectories). This study garnered such graphic predictions via mouse-click responses on a computer workstation—a method that greatly improves the accuracy, manipulability, and ease of analysis of the data.

With such data, we can ask—for instance—"Does the knowledge that ballistic objects move in curvilinear trajectories improve one's ability to predict the moment-by-moment positions of such an object, relative to subjects who have at least partially noncurvilinear, often impetus-like, models?" Consider a contrasting example: It is possible that subjects who have partially vertical or (at least partially) diagonal models of ballistic trajectories might have as good (or better) a sense of the magnitude of a projectile's motion as those who have more formally (e.g., parabolic-like) correct trajectory models. (Nb. that, obviously, a well-angled—if theoretically untenable—diagonal can better approximate an ecologically precise parabolic trajectory than can a parabola whose accelerative or linear vector components are either considerably exaggerated or highly underestimated.)

Other questions that can be addressed with this technology include: "Which sorts of pendular releases yield the highest response accuracy?" and "How similar are subjects' predicted trajectories when one compares situations that should have exactly the same basic (albeit sometimes reflected) form?" Due to space constraints, the experiment and analyses described below primarily focus on issues related to the first question; Ranney (1987, 1987/1988, 1988, in press) offers some answers to the second question.

Method

Subjects, Materials, and Apparatus

Forty undergraduate students (twenty male and twenty female) were paid to participate as subjects in this study. None of the subjects had ever taken either a high school or college physics course.

The materials included written instructions and a set of problem-sheets, each of which described a pendular situation that was about to be animated on the video monitor of a Xerox 1108 Lisp computer. The materials also explained how subjects could "draw" trajectories with the computer's mouse, and that they would be watching simulations of the pendular swing prior to the point at which the pendulum bob was supposed to be released from its supporting string. Eight pendular releases were described and animated (with the simulation "freezing" at the point of release): one from both endpoints, two from the midpoint/nadir of the swing (with prior motion both right and left), and two each from both an upswing and a downswing (also with prior motion both right and left).

Design and Procedure

Each subject was asked to predict the trajectories of the eight pendular releases by (a) watching a simulation until the release point and (b) placing "knots" on the monitor's screen with the mouse, such that the knots indicated the released pendulum-bob's position at various times after its release. Each subject was asked to put enough knots on the screen to follow the bob to the ground (about 'four meters' below; subjects usually generated ten or more knots). They could then edit their knots, moving each to another location—or even add new knots. Following this, lines on the screen were interpolated between the knots to let each subject view each trajectory in a more fluid form. Verbal protocols were also garnered, so subjects yielded converging descriptions about their graphically depicted trajectories (cf. Ranney, 1987/1988). When a subject was satisfied, s/he moved on to the next prediction, although miniature images of past predictions (at the side of the screen) were available for inspection, comparison, and change. All influences of any friction or air resistance were, by explicit instruction, to be ignored; hence, the ecologically veridical trajectories represent an idealized, "vacuum-contexted," Newtonian set.

Results

Coding the Data

The coordinates of each knot placed by a subject were recorded for the last trajectory that the subject predicted for a given release situation (i.e., after any modifications), and these were combined into a set. The set was then labelled as representing a particular trajectory "form," based upon the convergence of both the subject's verbal protocols and the appearance of the depicted trajectory. (Inter-rater reliability in the coding of such forms is quite high; see Ranney, 1987/1988.) The correct form for the endpoint releases are those coded as "S" for "Straight-down," while the correct form for the upward-releases is "Ca" for "Curvilinear-arch." "C," for "Curvilinear-down" is the correct form for the remaining (midpoint/bottom- and downward-) releases. (A finer distinction between parabolic and other curvilinear trajectories is unnecessary, as most of the subjects could not generate one.) See Figure 1 for some examples of complex trajectories that result when subjects combine these and other forms.

In contrast to the few correct forms, subjects generated dozens of trajectories—about forty unique codes in total. These include impetus-like variants that both curve down for a while and then fall straight down (C,S, which exhibits "dissipation"), others that initially move horizontally for some time (e.g., H,C, exhibiting "internal force"), and even more unusual ones that involve, for instance, trajectory segments that initially continue to follow a concave-up path (e.g., "Cu,Ca," highlighting "curvilinear impetus"). Some depicted paths even move retrograde relative to the lateral motion at the point of release (e.g., "R,<->" for "diagonally downward, but directionally reversed"). Ranney (1987/1988 & in press) describes these in more detail.

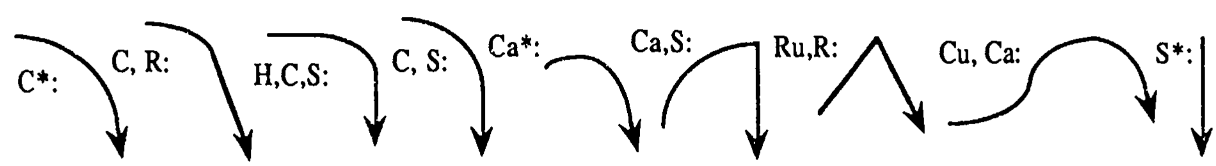

Figure 1. A small sample of subjects' dozens of inappropriate and three appropriate (*) trajectory forms, with their associated codes. (Ca is appropriate for upswing-releases, S for endpoints, C for the rest.)

Overall Performance on the Various Tasks

As subjects were told that the animated pendulum was a meter in length, and since its animation (e.g., period) was veridical, one can compare the set of each subject's knots, for each pendular situation, with the (respective) closest points on the veridical trajectory for the eight pendular releases. Overall, subjects placed their knots (totaling 2,612 coordinate pairs) an average of 261 pixels from a trajectory's origin (range: 4 to 789). The knots deviated from their veridical paths by an average of 93.3 pixels, about 35.8% of the mean distance from the origin. Releases stemming from a rightward swing (i.e., excluding leftward and endpoint releases), which were elicited first, produced less accurate predictions than those from a leftward swing (98.0 vs. 85.4 pixels). (Nb. all

differences described in this paper are significant at least at the $p < .05$ level, unless noted otherwise.) Although confounded with primacy, rightward releases also consistently yielded response trajectories that exhibited more lateral motion, compared to leftward releases (for both genders); such directional asymmetries are not uncommonly observed in perceptually related phenomena (e.g., Ranney, 1989, and associated articles on representational momentum and similar effects). Releases during a downswing produced more accurate knots (79.7 pixels' deviation) than those of either (a) lateral releases from the nadir (99.5 pixels) or (b) releases from an upswing (97.5 pixels) or (c) releases from the endpoints (97.1 pixels). These differences are not due to differences in the mean displacements of subjects' knots from the points of release, as these were all comparable (indeed, slightly greater for the more accurate downward-releases). This advantage for accuracy on the downward releases was also mirrored in the likelihoods with which subjects yielded paths of the correct form (cf. Ranney, 1987/1988).

Since these average deviation measures are fairly aggregative (cf. Ranney, in press), more telling are comparisons between instances of subjects who generated the appropriately correct forms and subjects who generated particular *in*correct forms. To illustrate the general frequency of this latter set of forms, it seems worth noting that half (four) of the tasks should have yielded "C" trajectories—yet various subjects generated 21 incorrect ("non-C") sorts of trajectory forms for them. The following sections contain analyses of such diverse responses.

Accuracies Among Formally Correct vs. Formally Incorrect Predictions

On average, only 21% of subjects' responses yielded formally correct predictions (although performance and consistency varies widely between subjects; Ranney, 1987/1988, in press). These subjects placed their knots only about 56.4 pixels away from where they should have been, while the overwhelming majority of subjects' paths, which exhibited incorrect forms, yielded nearly twice that average—a mean deviation of 102.3 pixels. (Again, the effect is not due to variations among the subjects' overall displacements of their knots from the origin.)

Several other patterns emerge from these deviational data. First, much of the correct vs. incorrect difference stems from the advantage one might get from knowing that endpoint releases yield vertical trajectories (Ranney & Thagard, 1988). Subjects who predicted "S" for these releases yielded a trivial average deviation of only 9.5 pixels, whereas subjects who predicted nonvertical trajectories exhibited a mean deviation of 116.4 pixels. Excluding these tasks (i.e., focusing only on the six interior pendular releases) yields a still-significant, but more modest advantage for subjects who provided correct-form trajectories (69.5 pixels vs. 97.8 pixels).

A second pattern relates to subjects who predicted paths that were retrograde with respect to the motion of the pendulum prior to the bob's release. (Verbal protocols show that most, if not all, of these responses were intended to be retrograde; they were not generally "mental slips" regarding the pendulum's prior motion.) Although relatively few in number (about 15 paths), retrograde trajectories yielded an average deviation of 196.9 pixels, and significantly increased the average deviation of paths with incorrect forms from what would have been only 86.3 pixels for the interior releases (and 94.1 pixels if the endpoint releases are included). Excluding both the endpoint releases and any retrograde trajectories, subjects who predicted the correct forms (C and Ca in this restricted set) at the appropriate times generally performed more accurately than those who did not (i.e., 69.5 pixels vs. 86.3)—although the former group's mean deviation is only about 20% less than that of the latter.

"Joe and 'Joanna' Montana Meet Einstein:" The Accuracies of Specific Forms

In general, male subjects were much more likely to depict paths with the correct form (about 33% vs. about 8% for females; cf. other such gender effects in Ranney, 1987/1988). This finding conflicts with conclusions from Kaiser, Proffitt, Whelan, and Hecht (1992), whose forced-choice data led them to suggest that simply animating pendular releases eliminates gender differences. Despite this difference, both genders were statistically equivalent in terms of their average deviation from the veridical paths (93.7 pixels for men, 92.9 for women). This indicates that, in terms of the difference between one's formal knowledge and one's kinesthetic intuition, there may be more "Joanna Montanas" (or perhaps "Martina Navratilovas") than "Joe Montanas."

Of particular interest is whether or not any incorrect forms yielded more accurate predictions than correct forms. Such forms existed for paths that should have yielded either C or Ca forms, but not for S forms. Specifically, subjects correctly yielding Curvilinear responses manifested a mean deviation of 77.5 pixels. Of the two (impetus-laden) incorrect trajectories that yielded significantly smaller deviations, only the C,S path (see Fig. 1) was reasonably frequent—i.e., about as common as the C response itself. The mean deviation for "C,S" depictions was 48.8 pixels, suggesting that people who correctly draw C responses actually overestimate the continuing lateral motion relative to the accelerative downward motion due to gravity. Although the "C,S responders" fall prey to the notion of dissipation (Ranney, 1987/1988, 1988), it actually seems to serve them better than does its absence serve their more Newtonian peers. Still, the "C responders" outperformed the accuracy evidenced from seven other path-forms. Statistical power was not high enough to reject equivalent-mean hypotheses for twelve other forms (if they are indeed inferior). Note that R responses were plentiful, yet, their average deviation (77.7 pixels) was virtually identical to that of the correct C corpus of data; the less frequent H,C

and H,C,S responses evidenced even (again, nonsignificantly) lower average deviations (67.4 and 73.0 pixels). The linear segments of these responses are indicative of the internal force type of impetus.

For the upswing releases, which should have yielded arching Ca paths, "Ca responders" outperformed 13 of 24 sets of alternative-form responders, and were themselves outperformed by three such sets. (Statistical power was lacking for determining the remaining eight contrasts, although four each were numerically lower than and higher than the mean Ca deviation.) In particular, the proper Ca paths yielded a mean deviation of 51.4 pixels, in contrast to those who offered the more accurate C paths (again, for Ca-appropriate releases; 14.3 pixels), "H,C" paths (14.4 pixels), and "C,R" paths (21.7 pixels). Although each of these incorrect forms were low in frequency, they each benefit from the fact that a release during an upswing generally has a fairly minimal segment of upward motion before the acceleration due to gravity moves the resultant velocity vector downward. Subjects responding with a Ca path generally overdramatized this upward segment, so some subjects who included either horizontal segments (e.g., H,C), well-angled diagonal segments (C,R—which is also indicative of the "internal force" type of impetus; Ranney, 1987/1988, 1988), or even fairly broad curvilinear segments (C) could outperform the subjects who responded with a more appropriate (but often over-) arching Newtonian form.

For the endpoint releases, which prove very difficult, no incorrect path-forms could match the vertical S form. Of 19 alternative forms, all but one had higher average deviations than the 9.5 pixels evidenced by subjects drawing the S trajectories. This obviously reflects the fact that nonvertical trajectories deviate considerably from easy-to-draw vertical trajectories. The only form that could not be rejected as inferior (again, probably due to the low power afforded by infrequent responses), included trajectories that curved rapidly into verticality (C,S).

Correlations Among Formally Correct vs. Formally Incorrect Predictions

A different measure of how well subjects' predictions approximate (most) correct trajectories is represented by the correlation between the y-coordinates of a subjects' knots and comparable y-coordinates from the veridical parabola (based upon the x-coordinates of subjects' knots). (This measure also controls for a potential, but not presently manifested, problem with the average-deviation measures reported above: that subjects may have placed more knots closer to the various release origins for some, especially nonlinear, predicted forms.) Since vertical (S) paths contain no variation in the horizontal dimension, correlations with such forms are improper; therefore, the following analyses are only with respect to the veridical parabolic trajectories for the six interior pendular releases (i.e., for releases other than those at the endpoint).

For the "appropriately-C" data (i.e., from subjects yielding "C" predictions for downward and lateral releases), the knots correlated at $r = .62$ with appropriate coordinates from the veridical, parabolic, "C" trajectories. This correct form was significantly better correlated than the inappropriate forms "Cu,S", "Ca", "S", and "C,S" (.14, .18, .20, and .39). The "C" form subjects' data were also marginally better correlated than those who predicted the diagonal "R" form ($r = .42$; $p = .06$), a finding that conflicts with one "Joe Montana" prediction explicitly mentioned above. Largely due to relatively few responses per "non-C" form, the remaining 16 inappropriate trajectory forms were not significantly more or less correlated with the veridical parabolic trajectory than the .62 from the "C" subjects. Even so, one odd and rare trajectory involving curvilinear impetus (e.g., Ranney, 1987, 1987/1988)—"Cu,R"—almost achieved such statistical significance, with a surprising $r = .99$ ($p = .076$).

The story was much the reverse for parabolic trajectories of the "Ca" form, largely because the period of upward movement from an upward pendular release is so short that subjects who focus on this portion often greatly exaggerate it. As a result, the "appropriately-Ca" subjects' data correlated only at .22 with the veridical, parabolic, "Ca" trajectories. In contrast, four of the 19 inappropriate forms obtained from the upswing tasks ("R," "C,R," the triangular "Ru,R," and the near-veridical "C") were significantly more highly correlated ($r = .61$, .76, .91, and .96); another form (H,C) was marginally superior ($r = .925$, $p = .07$).

Discussion, Conclusions, and Implications

These results suggest that subjects with more appropriate notions about the forms of ballistic trajectories generally—but certainly not always—yield more accurate and/or better-correlated predictions, compared to subjects who offer inappropriate (and sometimes almost bizarre) forms. Acting Newtonian was a distinct advantage for responding to the endpoint-release tasks, and was usually advantageous for the interior positions. However, by some measures, various paths indicative of one or more of three forms of impetus beliefs (dissipation, internal force, and curvilinear impetus) yielded responses that were either superior or equivalent to the correct forms. One modulating factor for these findings is the relative difficulty of the tasks involved. For instance, the situations that yielded the most evidence in favor of the alternative (and primarily disconfirmed) "Joe Montana hypothesis" was also one of the more difficult; subjects' trajectories for these upswing pendular releases yielded the lowest overall correlation between predicted knots and points from the veridical parabolae ($r = .14$, compared to .27 to .79 for the other types of releases), and manifested one of the highest deviation/displacement ratios (40%). Another factor is the overall approximate predictive similarity of many of the generated trajectories (e.g., a triangular vs.

an arching form) over distances that are perhaps modest in scale. Yet another factor involves relative expertise; more sophisticated subjects would probably increase their predictions' relative accuracies, especially if such subjects were offered measurements and less qualitative situations. Even so, given that some of these subjects who seem to best predict where a projectile will be at a given moment do so via considerably non-Newtonian drawings and explanations, we would do well to continue to seriously consider the question, "Does a theory rest in one's actions, or one's conceptions, or both?" (See Ranney, in press, for an elaboration on aspects of this question.)

Methodologically, this study demonstrates and highlights the utility of garnering graphically oriented "naive physics" data (in addition to other sorts of graphic data; Ranney & Reiser, 1989) via an interactive computer system. Many experiments continue to under-utilize the potential of such technology, often due to a variety of practical or theoretical apologia that may not hold up under closer scrutiny (Ranney, in press). The present method also offers other perspectives on real or alleged gender differences. Ranney (1987/1988) found many gender effects in the naive physics of motion (all favoring males—sometimes by a four-to-one ratio); still, these results also indicated that some disparities disappear (as shown by post-tests) with either more experience with the phenomena or nontheoretical feedback. Furthermore, the analyses reported presently show that women may perform as accurately as men in a rather ecological sense, even if their theoretical constructs may not be as formally "correct."

Finally, beyond the inherent interest to academic psychologists and cognitive scientists, the results of these analyses should interest science educators; the findings offer hints regarding the ways in which one should try to integrate a student's theoretical and pre-theoretical (e.g., informal, experiential, and kinesthetic) knowledge to yield both more optimal and more motivating educational curricula.

References

Caramazza, A., McCloskey, M., & Green, B. (1981). Naive beliefs in "sophisticated" subjects: Misconceptions about trajectories of objects. *Cognition, 9*, 117-123.

Kaiser, M.K., Proffitt, D.R., Whelan, S.M., & Hecht, H. (1992). Influence of animation on dynamical judgments. *Journal of Experimental Psychology: Human Perception and Performance, 18*, 669-689.

Ranney, M. (1987). *Restructuring Conceptions of Motion in Physics-Naive Students.* Manuscript of the paper presented at the annual meeting of the American Educational Research Association.

Ranney, M.A. (1988). Changing naive conceptions of motion. (Doctoral dissertation, University of Pittsburgh, Learning Research and Development Center, 1987.) *Dissertation Abstracts International, 49*, 1975B.

Ranney, M. (1988). *Contradictions and Reorganizations Among Naive Conceptions of Ballistics.* Manuscript of the paper presented at the annual meeting of the Psychonomic Society.

Ranney, M. (1989). Internally represented forces may be cognitively penetrable: Comment on Freyd, Pantzer, & Cheng (1988). *Journal of Experimental Psychology: General, 118*, 399-402.

Ranney, M. (in press). Relative consistency and subjects' "theories" in domains such as naive physics: Common research difficulties illustrated by Cooke and Breedin. *Memory & Cognition.*

Ranney, M., & Reiser, B.J. (1989). Reasoning and explanation in an intelligent tutor for programming. In G. Salvendy & M.J. Smith (Eds.), *Designing and using human-computer interfaces and knowledge based systems* (pp. 88-95). New York: Elsevier Science Publishers.

Ranney, M., Schank, P., Mosmann, A., & Montoya, G. (1993). Dynamic explanatory coherence with competing beliefs: Locally coherent reasoning and a proposed treatment. In T.-W. Chan (Ed.), *Proceedings of the International Conference on Computers in Education: Applications of Intelligent Computer Technologies* (pp. 101-106).

Ranney, M., & Thagard, P. (1988). Explanatory coherence and belief revision in naive physics. *Proceedings of the Tenth Annual Conference of the Cognitive Science Society* (pp. 426-432). Hillsdale, NJ: Erlbaum.

Schank, P., & Ranney, M. (1992). Assessing explanatory coherence: A new method for integrating verbal data with models of on-line belief revision. *Proceedings of the Fourteenth Annual Conference of the Cognitive Science Society* (pp. 599-604). Hillsdale, NJ: Erlbaum.

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Computer-based diagnostics in high school algebra: moving towards eloquence

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Abstract: A project to improve the quality of computer-based diagnosis of errors and their causes in grade 9 algebra is underway using data collected from students to improve researchers' understanding of the types and causes of errors frequently committed. The goal is to both improve the description of the behaviors to take into account the reasoning process underlying them as well as eventually developing a new algorithm for navigating through the item bank. Approximately 200 students completed 10-item tests. Preliminary analysis has confirmed the classification of item difficulty and is providing insights into the kinds of difficulties students have.

The *Laboratoire informatique d'évaluation et de didactique des mathématiques et des sciences (LIDÉ)* or *Laboratory for computer-based evaluation and teaching in mathematics and science* was created to help teachers improve mathematics and science education (Vázquez-Abad, Dassa, & René de Cotret, 1993). LIDÉ's projects all study effective instruction in mathematics and science at the secondary level. The effective instruction model favoured combines knowledge from evaluation and didactics to create teaching interventions aimed at optimizing the quality of learning.

Dassa (1991, 1993) developed a computer-based diagnostic system aimed at facilitating formative evaluation in geometry and algebra for Secondary II students (grade 8). In examining the effectiveness of the diagnoses that the system proposed, a new project was created with the principal objective of making the system's diagnoses more eloquent. In other words, develop a system that would describe in more precise terms the students' errors with a view to suggesting remediation possibilities or eventually ways of preventing these errors. The focus then is on the design of a computer-based diagnostic instrument to provide teachers with a picture of the individual difficulties their students are having, as well as a global portrait of the difficulties encountered by the class as a whole. To better guide teaching and remediation activities, the project is also exploring the conceptions underlying the students' difficulties. This integration of evaluation and didactics is promising for the development of powerful tools for teachers (Dassa & René de Cotret, in press; René de Cotret & Dassa, in press).

Description of present system

Imagine a bank of multiple choice items on a given subject. Each item has its place in a three dimensional structure where the axes represent the cognitive abilities, the notional content and the diagnostic context, organized hierarchically, from the easiest to the most difficult. (This structure was proposed by Auger & Dassa, 1991.) The farther the item chosen is from the intersection of the axes, the more difficult it should be to solve. As well, each item has four possible answers: one correct and three incorrect. The incorrect answers (distracters) are generated from common student mistakes, as identified by experienced teachers. It is therefore easy, when a student chooses an answer, to describe a possible cause of the student's error.

When a student completes a computerized diagnostic test on a given objective (i.e. the cognitive ability is fixed), the first question presented is of medium difficulty. If the student responds correctly, the second question is more difficult in terms of either the notional content or the diagnostic context. In the same way, if the student answers incorrectly, the next question will be easier. For example, if a question which asks the student to find the area of a triangle is not well answered, the notional content would be modified to ask an easier question concerning, for example, the area of a square. This kind of test is known as adaptive, as the items administered vary from one student to another with the navigation through the item bank being a function of the students' responses.

Desired modifications

Modifications to the current system are desired on two levels: 1) improving the description of behaviors to generate more discriminating distracters, and 2) improving the navigation through the item bank.

1) It is important that the identification of error causes be refined, with the descriptions becoming more eloquent in terms of the concepts underlying the choice of a given distracter. It is not sufficient to merely describe the behaviour which led to a given choice; from a teaching perspective, it is important to make hypotheses about the underlying concepts which can be used to guide remediation activities. This implies additional work in the definition of the domain of reference.

An example of this can be seen in the following sample item.

Find the equation that fits the following statement: By taking away 4 from the triple of the number y, we obtain 32.

a) $3y - 4 = 32$
b) $4 - 3y = 32$
c) $y^3 - 4 = 32$
d) $4 - y^3 = 32$

The diagnosis that goes with answer b is: "The student has inverted the two terms of a subtraction". While this is a correct description, it does not inform the teacher of the possible *causes* of the behaviour. Did the student just write down the numbers in the order presented in the problem? Or did the student not want to subtract a larger number (4) from a smaller number (3)? Obviously, these different causes imply different remediation activities.

2) The algorithm which controls the student's navigation through the item bank must be refined so that it takes into account not only the difficulty level of the items, but also looks at the specific distracter chosen by the student. By using the distracter as an additional input, the choice of items can test not only what the students know and don't know, but hypotheses about why they are making certain errors. In other words. given response b above, a problem would be given which had the same structure but reversed the numbers so that a student merely copying the order would have to subtract a larger number from a smaller one. In this way, the hypothesis about the cause of the student's error could be tested.

Information required to carry out these improvements

Approximately 200 secondary III (grade 9) students completed tests consisting of 10 questions chosen in a stratified random way from a bank of 70 questions. The questions had been rated by a team of researchers and high school teachers as easy, medium or difficult; each test comprised two easy questions, three medium, and five difficult chosen randomly from the subgroup. The tests were administered by the regular mathematics teachers during a class period; the students were not asked to provide any identifying information. The administration procedure resulted in a data pool of approximately 2000 questions for analysis.

We then developed a grid to facilitate analysis within and across problems and students (see Figure 1); for example, identify which problems seem to produce certain kinds of errors, students who consistently demonstrate certain behaviors, etc.

Élève #					
Item #	**Réponse (B/M/Ø)**	**Raisonnement (S/E/P/Ø)**	**Stratégie (Alg/Art/Tât)**	**Vérification (O/N)**	**Commentaires**
	/10				
Remarques synthèses :					

Figure 1: Analysis grid

The grid provides a record for each test of the student number (indicating which class the student was in and a sequential identifying number) as well as the numbers, listed in order, of the questions in the student's test. The following information is recorded for each question: whether the answer was correct, wrong or absent; whether the reasoning process was correct, incorrect, or partial (for example, the student began well but introduced inconsistencies later); if the strategy followed was algebraic, arithmetic or trial and error; whether the student verified his or her answer. The comments column provides space to elaborate; for example, on the problem-solving strategy used, the type of error committed, or why the reasoning was judged to be partially correct. The total number of correct answers is recorded for each student, followed by "synthetic" or general remarks which may help to characterize the student; for example, he made a similar error twice, she always used an algebraic strategy, it appears that language difficulties may be involved for this student. The analysis using the grid will be followed up by a closer examination of protocols identified as being of particular interest.

Although grids have not yet been completed on all 200 tests, certain interesting facts can be noted from the 80 which have been examined so far.

Classification of questions

In looking at the success and failure rates of the students as a whole for the different questions, we observe that our initial classification of questions according to difficulty is well-supported by the students' results. This means that we can now proceed to a more detailed analysis of what makes a given question easier or harder: is it the form of the equation, the context in which it is set, the facility with which different strategies can be applied or some interaction of these elements. The results of this analysis will allow us to determine the classification criteria for the new bank.

With respect to problem-solving strategies, the algebraic approach is used more often, irrespective of the level of difficulty of the questions. However, there appears to be a trend towards a decrease in the frequency of algebraic strategies and an increase in arithmetic and trial and error strategies as the problems increase in difficulty. Is the decrease in algebraic strategies due to the fact that the strategy is not fully mastered and can only be used when the problem is relatively easy or presented in a very traditional form? Is the increase in the other strategies due to students taking refuge in more familiar or better understood strategies as problems increase in difficulty? These questions will be examined in some detail when the preliminary data analysis is completed. Not surprisingly, the percentage of problems not answered increases as the difficulty increases.

Just as certain kinds or levels of problems may elicit algebraic or arithmetic strategies, we can also examine the response patterns of different students to see if there are individual preferences. It would appear that some students systematically apply algebraic strategies while others can be characterized as "arithmetical" students. There are also students who vary their strategies according to the specific problem.

We have also identified certain errors which appear to be common across students. For example, a student considers (incorrectly) two unknowns to be equal. The following problem illustrates this:

A man invests \$4,000, part at an annual interest rate of 5% and the rest at 3%.
After one year he receives \$168 in interest. How much did he invest at 3%?

The student writes the following equation, $5x + 3x = \$168$, assuming that the two amounts were equal. This type of error seems to be associated with problems which can be expressed in the form of: $ax + b(T-x) = c$. In other words, problems which require two equations, one of which is $x + y = T$ which can be transformed to express y in terms of x. This error appears to be characteristic of this kind of problem. The student protocols will be studied in detail to identify the reasoning underlying this error type. It is likely that certain students often commit the same type of error, independent of the question asked. The analysis undertaken so far has allowed us to identify only a few cases, but this is one area we will be focusing on when the grids for the 200 tests are completed.

By examining the entire data pool, we will be able to detect other patterns of errors associated with either students or problems. We will then proceed to the analysis of the reasoning processes associated with the different error types. This work will contribute significantly to the clarification of the domain of reference, an essential step before subsequent refinements can be considered.

Implications of this work for computer-based diagnosis

Results of this project will have a number of important effects. First, they will allow us to create more effective diagnostic tests because with more insight into the probable causes of the errors, remediation will be easier. These tests should help in the teaching and learning of high school algebra. As well, the research project should permit both researchers and practitioners to develop a better understanding of the content area.

A third outcome will be to look at to what extent the algorithm developed for these tests will be exportable or adaptable to other content areas, mathematical or other. Is it possible to elaborate a navigational schema which will respond to the specific needs of mathematical diagnosis which will also be generalizable to a variety of disciplines?

References

Auger, R. et Dassa, C. (1991). L'intégration du diagnostic interactif à l'évaluation formative informatisée des apprentissages scolaires. *Actes du Colloque international de l'Association Francophone Internationale de la Recherche Scientifique en Éducation.* Carcassone, France.

Dassa, C. (1993). Régulation des apprentissages, contexte de mesure et évaluation informatisée. In R. Hiron (Éd.), *Évaluation des apprentissages,* Sherbrooke: Université de Sherbrooke.

Dassa, C. (1991). Battery of computer-based diagnostic tests for mathematics (Secondary II). Item bank (2000 items; 16 adaptive tests) and programming for MicroCAT. Disks and manuals.

Dassa, C. & René de Cotret, S. (in press) Validation d'un système informatisé de diagnostic en mathématiques au secondaire: une approche centrée sur l'analyse didactique. *Mesure et évaluation en éducation.*

René de Cotret, S. & Dassa, C. (in press). Utilisation d'un système informatisé de diagnostic pour l'évaluation formative en mathématiques au secondaire. In *Proceedings of the 45th meeting of the International Commission for the Study and Improvement of Mathematics Teaching*. Cagliari, Italy.

Vázquez-Abad, J., Dassa, C. & René de Cotret, S. (1993) Computer-Based Science and Mathematics Instruction and Evaluation: A Joint Industry, School and University Project in Secondary Education. In *Rethinking the Roles of Technology in Education,* N. Estes & M. Thomas (Eds.). Austin: The University of Texas at Austin, pp. 799-801.

Accentuating Problem-Based Learning with Technology

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Abstract: Problem solving is a universal function. Throughout our lives we encounter ill-defined challenges that require us to draw upon our problem-solving skills to reach effective solutions. A traditional approach to teaching problem solving is to present students with well-defined problem parameters that lead to predetermined outcomes. An alternative approach that is gaining interest among professional educators is that of problem-based learning. With this method teachers generate problems to resemble realistic, ill-defined situations students confront in everyday life. Students are then given opportunities to analyze the problem, identify known and unknown components, collect data, formulate potential solutions, and derive what they consider the best solution. Although theories and practices exist which assist this pedagogy, tools to assist with these procedures are rare. This article examines the theory and recent changes in problem-based learning and describes a set of tools which (a) assists instructors with formation of problem-based scenarios, and (b) provides students a robust environment in which to analyze problems, collect data, structure solutions, and present findings.

Introduction

One of the most critical tasks we inherit as educators is the preparation of students to solve spontaneous, real-life problems as they engage in activities outside the classroom. Recent national attention has focused on this issue by declaring the need for students to increase their "ability to reason, (and) solve problems," (U.S. Department of Education, 1991, p.38) and that instead of teaching through drill and practice, students should work at "solving the problems they help design" (Reich, 1990, p. 201). However, even though many of today's real-world issues are within the realm of student understanding, the skills needed to tackle these problems are often missing from classroom instruction. This neglect may be due to one or more of the following reasons; (a) teachers may not understand the importance of activities which promote problem solving, (b) teachers may not know how to generate appropriate problems or establish classroom activities conducive to problem solving, or (c) the additional time required to implement problem-based learning my not appear justified in an already busy schedule. The purpose of this article is to address these concerns. This is accomplished by providing background information on problem-based learning, exploring conditions which maximize the transferability of classroom activities to real-life problems, and describing a recently developed tool designed to assist teachers and students in creating and solving problem-based learning scenarios.

The importance of problem-based learning

To provide proper education, it is imperative that we help children assimilate strategies and skills required to anticipate and solve problems in the emerging high-performance work place of the future. Currently, teaching strategies as diverse as problem-based learning, deductive and inductive reasoning, stages of moral development, ethics education, collaborative learning, metacognitive skills, and habits of mind all contribute to taking the student beyond the learning of simple facts, concepts, and procedures (Stepien, Gallagher, & Workman, 1993). One of the most useful of these strategies is problem-based learning (Barrows, 1985). Not only does this method allow for acquisition of content-relevant knowledge, but also the ability to transfer critical thinking skills to new domains and maintain a high level of motivation in the learning environment (West, 1992). The ability to analyze novel situations and determine appropriate action is becoming increasingly important, yet most

educators would agree that it is impossible to teach students all they need to know. Therefore it is critical that we develop within students the ability to solve problems yet to be discovered or identified (Smith & Good, 1984). The ability to solve problems, however, is more than just accumulating knowledge and rules; it is the development of flexible, cognitive strategies which can analyze unanticipated, ill-structured situations and produce meaningful solutions.

Unfortunately, instruction to help students develop skills in problem solving is seldom included in classroom instruction. Problem solving, as it is currently taught, tends to be situation specific and non-transferable. Typical problems are well defined, require a specific algorithm for their solution, and have one right answer provided by an expert. In these situations, it is often the procedure required to solve the problem that is the focus of instruction. Examples of these well-structured problems are commonly referred to as "word problems":

> Two trains leave stations 1264 miles apart at exactly the same time.
> Train A travels in an easterly direction averaging 53 mph. Train B . . .

Real-life problems seldom parallel these well-structured problems; hence, the ability to solve traditional problems does little to increase relevant, critical thinking skills students need to interact with life beyond classroom walls. Sterile environments in which there is only one right answer simply teach students *about* problem-solving, not *how* to problem solve. In real life, we seldom repeat exactly the same steps to solve problems; therefore, the lock-step solution sequence taught in well-structured classroom problems is seldom transferable. Instead, real-life problems present an ever-changing variety of goals, contexts, contents, obstacles, and unknowns which influence how each problem should be approached.

To strengthen transferable, critical thinking skills, students need to practice solving problems which reflect real-world variables in ill-defined scenarios. Real-world contexts and consequences not only allow learning to become more profound and durable (US Department of Labor, 1992), but provide an apprenticeship to solving real-life problems (Stepien et al., 1993).

To reflect real-life situations, classroom problems should incorporate the vagueness that is associated in problems we encounter in life. Seldom is a problem grasped at first sight, and seldom do we receive all the information required for solutions at one sitting. Therefore, classroom problems should be intentionally ill-defined, and information to solve the problem should not be handed out to students as they begin the problem. Instead, as students work through the problem they should feel the need, and be provided with the opportunity, to gather additional information to form potential solutions. Although new information may lead to dead ends, false starts, or recursive thinking, new insights into the problem often arise as student understanding develops (Barrows, 1985).

Designing problems

To reflect real-world constraints, problems provided to students should encourage active engagement, extend over time, provide realistic and contextualized situations, include key concepts or processes for students to master, and require that solutions include the development of a product (Krajcik, 1993). The more thoroughly these variables are integrated into problem-based learning in the classroom, the stronger the transferability to problems encountered after school.

Active engagement is promoted when we require students to ask and refine questions, design plans to collect and analyze data, develop and evaluate potential solutions, and share ideas and conclusions. By actively involving students in multiple aspects of the learning process, students are more likely to construct personal, meaningful knowledge of the subject. Personal knowledge is more highly ingrained, and therefore more easily transferred, to new situations than traditional classroom or school-based knowledge (Krajcik, 1993). Classroom knowledge develops when students learn information in more passive and sterile conditions. This often includes memorizing individual facts or procedures. Although these knowledge structures may help students produce answers for tests, students who learn information with a minimum of active engagement are often unable to derive adequate solutions or explanations when presented with similar questions or exposed to conditions outside the classroom environment.

This difference between classroom and personal knowledge is examined in constructivist learning theory, which views knowledge as being individually constructed through interactions with the environment. Constructivists believe that few issues in the world have a single, correct answer. Children in school, however, usually perceive that knowledge is either right or wrong, and that experts, teachers, or school books have the right answers or know ways to figure them out (Perry, 1970). Constructivists believe knowledge resides in the individual rather than existing in the world independently (Duffy & Jonassen, 1992). Because knowledge develops as individuals interact with the environment, learning is most meaningful when similar conditions are mimicked in the classroom. Constructivists also believe that because most post-school activities and learning are done in social settings with colleagues, school instruction should employ cooperative learning formats.

Group activities provide opportunities to express opinions, receive feedback, hear alternative perspectives, and discuss findings. Active participation fosters continual problem reflection and reformation of knowledge structures.

Constructivist believe that knowledge is situated in experience. The more authentic and contextualized the learning experience, the greater the ability to transfer procedures to daily experiences. Problems which include multidisciplinary aspects and are tied to current events help reduce artificial distinctions between life in the classroom and life outside school. Inspiration for developing problems comes from brainstorming with colleagues, news articles, or students themselves. Although teachers may need to help refine original statements, problems that students suggest are often those that actively engage students.

Although problems often reflect multidisciplinary objectives, they are generally based in a specific subject domain in which concepts and processes are to be learned. In creating problems, instructors should (a) identify facts, concepts, procedures, and principles which students will uncover as they work towards their solution, (b) identify an appropriate problem which will guide students towards uncovering the material, and (c) determine students' informational needs and make information available as needed during the problem solving activity. Teachers should start by identifying knowledge structures students should develop by the completion of the problem. The process of determining the end knowledge and working back to identify the initial problem will help increase the probability that appropriate information will be conceptualized as students work through the problem situation.

Problems which engage students over a period of time by requiring a series of activities or exercises to be solved better reflect and prepare students for future situations. Problem-based learning activities should be structured so that students perceive the complexity of real-world problems. This can be accomplished by presenting problems that are composed of multiple parts, each of which is a problem in its own right. Through practice with complex, ill-structured problems in the classroom, students may realize that many of life's problems are more easily solved when large problems are divided into more manageable subproblems.

At the completion of the problem, it is important for students to bring the process to closure by creating products which demonstrate their knowledge. Sharing conclusions or products with teachers, students, parents, or the public provides both an audience to judge the worth of the solution and raises the process from an academic exercise to one which more accurately reflects real problem-solving procedures of adults.

As students work with problem-based instruction, the instructor's role should be more as a mentor or cognitive coach, providing guidance rather than delivering content information. In these learning environments, it is often appropriate for instructors to answer students' questions with one of their own. Replying with a question encourages students to redirect their thought processes and helps guide students toward the development of personal perceptions and meaning. Examples of such questions might include: Where could you find more information about that? or What would you want the information to tell you?

The Problem-Solving Assistant

Unfortunately, teachers frequently lack sufficient time or knowledge to generate relevant and robust problem-based learning activities. Also, students often lack the metacognitive skills needed to gather and analyze data, generate and test hypotheses, and evaluate, justify, and present solutions to problems (Stepien et al., 1993). To help alleviate these obstacles, the authors have developed a template to assist instructors and students in the creation and use of problem-based learning situations. The template, known as the Problem Solving Assistant (PSA), was designed to promote problem-based learning for science students in middle school using an anchored instruction approach similar to that used in the Jasper experiment (Cognition and Technology Group, 1992). Anchored instruction is "situated in engaging, problem-rich environments that allow sustained exploration by students and teachers" (p. 65).

The PSA presents its users with a 'study room' metaphor which is intended to simulate an environment where students would typically conduct research in pursuit of a problem solution. The study room provides a relevant, context-rich learning environment in which students experience near-authentic situations. The study room metaphor has been incorporated not only because it represents a context with which students are familiar, but because metaphorical representations have been found to facilitate learning and far transfer of knowledge (Andre, 1986). The room has a variety of research resources including reference books, CD-ROM player, television, videodisc player, telephone, computer, and bulletin board. As students interact with these objects, they become actively involved in the learning process by analyzing the problem, collecting relevant data, and deriving solutions. This active involvement helps knowledge acquisition become personal, meaningful, and memorable.

The PSA contains two modes of operation, an "author mode" and a "user mode". In the author mode, the PSA provides instructors the flexibility to generate problems appropriate to their students' levels of

understanding. In adapting material, instructors are prompted to identify an appropriate problem to guide students towards relevant content material and make available information for the problem solving activity. To support the problem solving process, instructors embed conceptual and procedural information within PSA tool. The instructor may employ the entire spectrum of media to present this information via on-line access to videodiscs, QuickTime movies, audio clips, pictures, graphics, and text-based materials. PSA provides a high degree of atomization to aid in the addition of this information, allowing the instructor to concentrate on the adaptation of materials and not on the mechanics of constructing a rich environment.

In the user mode, the PSA guides the student through the process of formalizing a description of the problem, gathering data about the problem, and constructing, analyzing, and presenting potential solutions to the problem.

The PSA allows students to explore the problem specific information added by the instructor. Students gain access to information by clicking on objects found in the study room. For example, to read instructor embedded text, students click on one of the textbooks on the bookshelf; to see a QuickTime movie, students click on the TV; to hear an audio clip, students select the telephone.

An important component of the PSA learning environment is the "Problem Log". The problem log prompts users through an eight-step problem-solving heuristic. This heuristic includes:

- Redefine the problem in students' own words.
- Delineate personal knowledge which may be used to reach a solution.
- Break the problem into manageable subproblems.
- Identify where pertinent information to the problem may be found.
- Collect relevant data.
- Generate potential solutions.
- Identify advantages and disadvantages to each potential solution.
- Determine the best solution.

Although these steps can be viewed as discrete and employed in the sequence shown, more often they distort and fold into one another as they are repeatedly visited by students in the problem solving process.

After an initial problem is presented, the problem log prompts students to restate the problem in their own words. As students examine and redefine the problem, they mentally transform a representation of the problem into personal memory structures, thereby making the problem and related knowledge more meaningful (Andre, 1986). This process helps refine their representational skills and provides for the construction of strong links between prior and new knowledge through reflection and examination.

After the problem statement has been defined, the problem log prompts students to identify personal knowledge of the context, content, or other characteristics which may be relevant. This procedure activates prior knowledge and, when done as a group activity, provides new information to students as communal knowledge evolves. As existing knowledge is solicited, areas in which students lack specific information are identified. Because subproblems may need to be examined and analyzed before the initial problem can be solved, the original problem often mutates as students work in recursive fashion towards the solution. To help students identify what they know and don't know, a question matrix is available to assist in examining their knowledge. The matrix prompts students to critically question their knowledge and encourages critical thinking needed for decision making and problem solving (Weiderhold,1981, as cited in Langrehr, 1993).

After students identify areas in which their knowledge is lacking, they are prompted to generate ideas where this knowledge may be secured. With access to on-line optical storage devices, audio and video clips, graphics and pictures, and text-based resources through their study room interface, and outside resources such as library books, telecommunications, and community experts, students should be able to identify a wide variety of sources from which to collect information. The more resources available to students, the closer the learning environment reflects real life.

After potential resources for knowledge collection are identified, students begin to gather data. Often data gathering illuminates areas of conceptual weaknesses and serves as a springboard in identifying additional areas of knowledge which must be gained before the initial problem can be solved. Eventually, data collection reaches a point at which students can begin to generate potential solutions. Because problems rarely have one potential solution, the log book prompts students to generate several alternatives. Students are then prompted to contrast solutions on a cost/benefit ratio and to identify the best alternative.

In addition to examining the problem and arriving at solutions, it is important for students to generate an artifact or product that describes or shows their solution. The PSA assists this step by providing a "presentation maker" which consolidates pertinent data which students generated earlier and assembles it in a format suitable for presentation. In addition to merging the problem, subproblems, data, and solutions into an editable format, the presentation maker also provides a title screen for problem identification and credits, and a summary screen for closure statements.

The PSA interface allows users to move between components either from a menu bar or by clicking their mouse cursor on different objects. Together, the components in the PSA can present the problem to the students, prompt students through a problem-solving heuristic, allow opportunities for students to gather data, and structure a presentation format. By providing an intuitive interface in which teachers structure and students solve problems, the PSA tool makes problem solving an easy yet enriching classroom activity.

Summary

Problem-based learning is an instructional strategy used to help learning become more personal and memorable. In problem-based learning, students are presented with ill-formed problems which do not require attainment of one "right" answer. Because these problems tend to mimic real-life challenges students face after school, knowledge gained through problem-based learning is often more transferable and generalizable than knowledge gained through more traditional instruction.

Unfortunately, the use of problem-based learning has not yet been widely incorporated in education. Members of the Department of Educational Technology at San Diego State University developed a tool called The Problem-Solving Assistant to assist the design, development, and implementation of problem-based learning. The tool prompts teachers and students through the problem-solving sequence by providing a series of prompts and a rich, interactive environment to guide the process. It is hoped that through the use of this tool, problem-based learning will be more widely adopted within classroom instruction. For further information on the PSA and to receive a free copy of the latest version of the software, contact Donn Ritchie at (619) 594-5076 or e-mail at dritchi@ctp.org.

References

Andre, T. (1986). Problem-solving in education. In G. D. Phye & T. Andre (Eds.), *Cognitive classroom learning* (pp. 169-204). Orlando, FL: Academic Press, Inc.

Barrows, H. (1985). *How to design a problem-based learning curriculum, the pre-clinical years.* New York: Springer-Verlag.

Cognition and Technology Group. (1992). The Jasper experiment: An exploration of issues in learning and instructional design. *ETR&D, 40*(1) 65-80.

Duffy, T. M. & Jonassen, D. H. (1992). Constructivism: New implications for instructional technology. In T. M. Duffy & D. H. Jonassen (Eds.), *Constructivism and the technology of instruction.* (pp. 1-16). Hillsdale, NJ: Lawrence Erlbaum Associates.

Gallagher, S. A., Stepien, W. J., & Rosenthal, H. (1992). The effects of problem-based learning of problem solving. *Gifted Child Quarterly. 36*(4). 195-200.

Krajcik, J. S. (1993). Learning science by doing science. In B. Yager (Ed.), *What research says to the science teacher.* pp. 53-58. Washington, DC: National Science Teachers Association.

Perry, W. (1970). *Forms of intellectual and ethical development in the college years: A scheme.* New York: Holt, Rinehart and Winston.

Reich, R. (1990). Redefining good education: Preparing students for tomorrow. In S. B. Bacharach (Ed.) *Education reform: Making sense of it all.* Boston: Allyn and Bacon.

Smith, M. U. & Good, R. (1994). Problem solving and classical genetics: Successful versus unsuccessful performance. *Journal of Research in Science Teaching, 21*(9), 895-912.

Stepien, W. J., Gallagher, S. A., & Workman, D. (1993). Problem-based learning for traditional and interdisciplinary classrooms. *Journal for the Education of the Gifted. 16*(4) 338-357.

U. S Department of Education. (1991). *America 2000: An education strategy.* Washington, D C: U. S. Government Printing Office.

U. S. Department of Labor. (1992). *Learning a living: A blueprint for high performance.* Washington, D C: U. S. Government Printing Office.

West, S. A. (1992). Problem-based learning - a viable addition for secondary school science. *School Science Review. 73*(265). 47-55.

Langrehr, J. (1993). Learning how to question information. *Teaching, Thinking, and Problem Solving 15*(1) 1-5.

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A model of reasoning and a model of explanation process for algebra

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Abstract : This paper presents a framework for learning polynomial factoring with interactive educational software. We consider problems which are solved by successive transformations of algebraic expressions, factorization of polynomials, equation solving, inequation solving... We propose a general model of reasoning called MCA (Model of Compiled knowledge in Algebra) and a general model of explanation called MGE (Model based on Grammar of Explanation). This two models have implemented in the APLUSIX project.

The design of Interactive Learning Environments (ILEs) in problem solving requires the modelling of the knowledge domain for solving exercises and explaining the resolution done. Our work is situated in the framework of human learning of algebraic problem solving with new technologies. The domains we are working on are polynomial factoring and equation solving. They are complex domains involving mathematical objects and algebraic representations, and requiring efficient strategies. The algebra exercises, at school, are usually limited to direct application of some rules. They are an excellent ground for the discovery learning. Most of the time, only factual knowledge and know-how are taught; exercises are applications of that knowledge and there is very little place for discovery learning.

Learning strategies can be done principally in two ways : (1) by observing some examples: the student follows some reasoning and try to discover the strategic knowledge, (2) by experience: the student performs some reasoning and try to invent some heuristics to improve his efficiency. In each situation, the environment can be crude or pedagogical ; in the second case, the student has access to the explanations justifying the action applied. In this paper, we consider only the first type of learning strategies. Thus, we propose a framework which encompasses two models : MCA model (Model of Compiled knowledge in Algebra) and MGE model (Model based on Grammar in Explanation).

This two models adresses a wide variety of algebraic problems and can be instanciated if we consider subclasses of problems. They have been implemented in the framework of the APLUSIX PROJECT (Nicaud et al 90).

Reasoning Model

The MCA model is based on a distinction between declarative and compiled knowledge as in the ACT theory (Anderson, 83; Anderson et al, 90) and on a heuristic search mechanism (Pearl, 85). We consider formal algebraic problems that people solve by successive transformations of algebraic expressions, like simplification of expressions, factorisation of polynomials, equation solving until a solved form is reached (Nicaud & al, 90). The MCA model involves sophisticated knowledge: transformation rules, plans, sub-problems, meta-strategies. A transformation rule is an operator that enables an expression to be transformed. A transformation is either a rewriting rule or generated by a composition of identities. The transformation rules are divided into subsets according to different level of expertise.

We define a static plan as predefined combinations of actions (Saïdi, 91). It is a recorded piece of knowledge and the result of planning process (which is dynamic plan). Plans decompose problems in sub-problems. An example of plan in the domain of factorisation of polynomials is :

IF	a sub-expression E of the problem is a sum
AND	an expression U can be factored out in part of E
AND	the partial factorisation of U in E produces a new expression V
AND	V is a possible factor of another part of E
THEN	factor out U
	develop and reduc the result of the factorisation
	factor out V
	develop and reduc the result of the factorisation

This plan invokes four successive actions. No strategic reasoning is done between two actions of a plan. Actions are calls to general tasks or well known subtasks like factor out U, arrange the result of the factorisation. The characteristics of the plan needed in this domain are: (1) plan cannot fail, (2) plan generally does not lead to the solution. We have shown that a strategy is embedded in a plan, but other strategies are necessary: strategies for choosing between several plans corresponding to the same problem, meta-strategy for starting/stopping some evaluation process according to general principles like complexity of generated expressions, number of step... The problem solving component has been designed to try to model human reasoning. The resolution process can be described as following: (1) develops a search tree for a problem by applying rewriting rules according to the replacement of equals inference mode, (2) defines sub-problems, (3) inserts results of sub-problems in problems.

The MCA model includes domain tasks. Domain tasks are problems decomposed in simple task, with an associated set of transformations, and complex tasks, with a static plans and a set of heuristics for choosing plans. Three generic tasks interpret simple tasks, complex tasks and plans. The MCA model also encompasses a set of a matching mechanisms for transformations and plans (Saïdi, 92).

With this model, we have developped the APLUSIX M1-V1 system (Saïdi, 92) for the domain of equation solving (polynomial equations and equations with radical signs). This system is an observation environment, i.e., it shows the student how it solves problems but does not allow the student to solve the problems. An example of problem solved by the system is shown in figure 1.

RESOUDRE

$\boxed{\sqrt{x^4+5x^3+11x^2+8x} = x+4}$

⇓ carré des deux membres

$\boxed{x^4+5x^3+11x^2+8x = (x+4)^2 \quad \text{et} \quad x+4 >= 0}$

⇓ transposition

$\boxed{x^4+5x^3+11x^2+8x-(x+4)^2 = 0 \quad \text{et} \quad x+4 >= 0}$

⇓ développement

$\boxed{x^4+5x^3+10x^2-16 = 0 \quad \text{et} \quad x+4 >= 0}$

⇓ racine évidente 1

$\boxed{(x-1)[x^3+6x^2+16x+16] = 0 \quad \text{et} \quad x+4 >= 0 \quad \text{abandon}}$

↓ différence de deux carrés

$\boxed{[x^2-4][x^2+4]+5x^3+10x^2 = 0 \quad \text{et} \quad x+4 >= 0}$

⇓ différence de deux carrés

$\boxed{(x-2)(x+2)[x^2+4]+5x^3+10x^2 = 0 \quad \text{et} \quad x+4 >= 0}$

⇓ mise en facteur de x^2

$\boxed{(x-2)(x+2)[x^2+4]+x^2(5x+10) = 0 \quad \text{et} \quad x+4 >= 0}$

⇓ mise en facteur de $x+2$

$\boxed{(x+2)[(x-2)[x^2+4]+5x^2] = 0 \quad \text{et} \quad x+4 >= 0}$

⇓ développement

$\boxed{(x+2)[x^3+3x^2+4x-8] = 0 \quad \text{et} \quad x+4 >= 0}$

⇓ racine évidente 1

$\boxed{(x+2)(x-1)[x^2+4x+8] = 0 \quad \text{et} \quad x+4 >= 0}$

⇓ division par x^2+4x+8 (expression sans racine réelle)

$\boxed{(x-1)(x+2) = 0 \quad \text{et} \quad x+4 >= 0}$

⇓ décomposition

$\boxed{(x+2=0 \quad \text{ou} \quad x-1=0) \quad \text{et} \quad x+4 >= 0}$

⇓ expression de la variable

$\boxed{(x=-2 \quad \text{ou} \quad x=1) \quad \text{et} \quad x+4 >= 0}$

⇓ vérification

$\boxed{x=-2 \quad \text{ou} \quad x=1 \quad \text{résolu}}$

Figure 1 : A resolution performed by the APLUSIX system. A double arrow represents the application of a transformation rule. A simple arrow represents the begenning of a sub-task.

Explanation Model

The M.G.E. explaining model encompasses two kinds of knowledge: explaining domain knowledge and strategic knowledge. The explaining domain knowledge involves the domain fact such, the student model and the historic explanation. The strategic knowledge determines the explanation strategy to apply for (re-)explaining the corresponding concept . The explanation module has been implemented as a reasoning process which generate information depending on the question and according to several explanations concepts. It produces extensive (multi-paragraph) explanations (Lestet & Porter, 91). To generate extended explanations, we use a top-down strategy. First, we define the general structure of the final text. By general structure, we mean basic blocks (Mooney & al, 91) composing the structure according to a grammar defined. Only after the basic bloc structure has been established will detailed realization into text proceed. The system uses the meta-strategic knowledge for choosing the appropriate strategies to generate the final text.

Different types of questions are allowed : questions about matching and questions about strategy. The first kind of question is asked when the student does not understand how an extended matching is performed. In this case, the system gives explanation by presenting description of the rule and the critical intermediate transformations. The second kind of questions is more complex to respond. This questions, about strategy, may be either of type why is it good action ?, or of the type I would propose another rule I will indicate, explain to me why it is not the best way to manage.

The MGE model has been also implemented in the APLUSIX M1-V1 system. The explanation module is able to indicate to the student the current task, the current plan and the current action, see figure 2a, 2b, 3c.

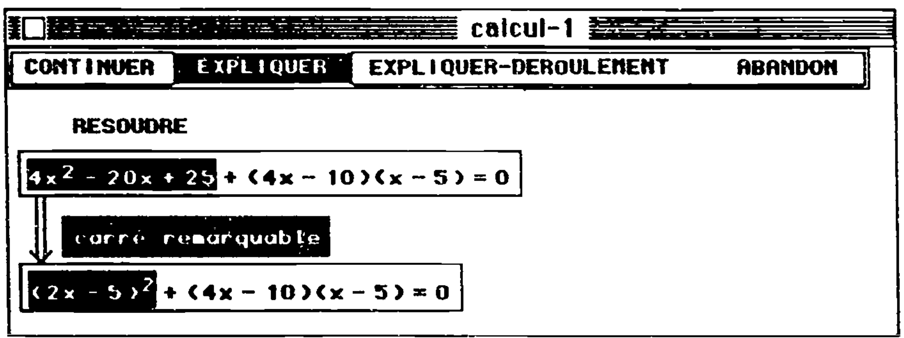

Figure 2a: The student ask for explanation at this point.

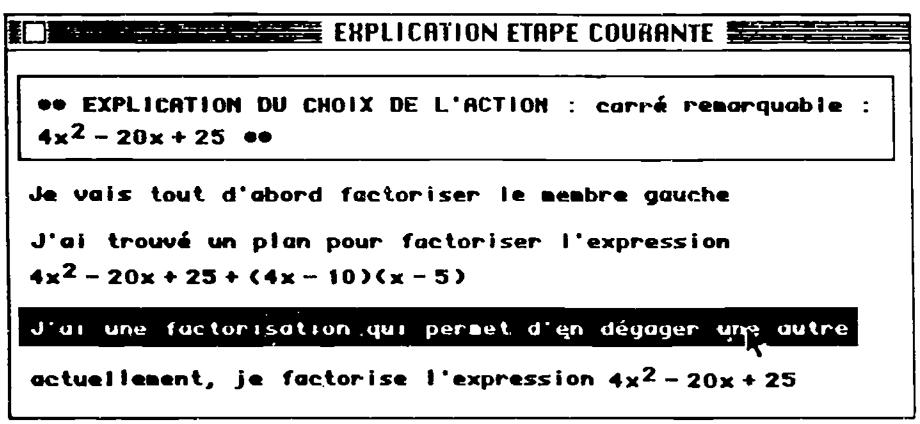

Figure 2b: The explanation includes information about the current plan and the current task. The student ask for more explanations concerning one point.

EXPLICATION SUITE

la factorisation de $4x^2 - 20x + 25$ produit $(2x - 5)^2$; cela dégage un facteur commun pour l'expression englobante $(2x - 5)^2 + (4x - 10)(x - 5)$

Dans cette situation, on a en plus : $2x - 5$ est un facteur commun dans l'expression totale $(2x - 5)^2 + (4x - 10)(x - 5)$

Figure 2c: Complementary explanations given by the system.

References

Anderson J. R. [83]: The Architecture of Cognition. Harward University Press.

Anderson J.R., Boyle C. F., Corbett A. T., Lewis M. W. [90]: Cognitive Modeling and Intelligent Tutoring. Artificial Intelligence, Vol 42, no 1.

Gélis J.M. [93]: Un cadre général pour une modélisation cognitive et computationnelle de l'algèbre. LRI report, Paris 11 University. To appear.

Nicaud J.F., Aubertin C., Nguyen-Xuan A., Saïdi M., Wach P. [90]: APLUSIX: a learning environment for acquiring problem solving abilities. Proceedings of Cognitiva 90, Madrid.

Saïdi M. [91]: Planification et explication du raisonnement d'un résolveur complexe en algèbre: application aux factorisations de polynômes et aux résolutions d'équations. Première rencontre des jeunes chercheurs en IA, Rennes, Septembre 1991.

Saïdi M. [92]: Planification et explication du raisonnement d'un résolveur complexe en algèbre: application aux factorisations de polynômes et aux résolutions d'équations. Thesis, Paris 11 University.

Pearl J. [85: Heuristics. Addison-Wesly, 1985.

Lestet & Porter. [87]: An architecture for planning Multi-paragraph Pedagogical Explanations. AAAI-91 Workshop..

Mooney & al. [92]: The need for bottom-up strategies for generating High-level structure. AAAI-91 Workshop.

Groupwork in science: the influence of gender

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Abstract: This paper uses the outcomes of some Open University research projects to examine the implications of the effects of the gender composition of groups studying science and using the computer. The cognitive benefits students gain from learning in groups have been widely advocated, and recent curriculum moves towards encouraging investigative learning in science for a variety of different age groups have highlighted the importance of group learning. However there are few detailed accounts which both investigate the processes which operate in groups tackling investigative science tasks and the way in which these processes can support the childrens' and adults' science learning. In this paper I will concentrate the gender aspects of some research projects which involve students working in groups with computers on science topics.

Introduction

Studying science has become a group activity. Students are encouraged to engage with their peers in carrying out both intellectual and practical tasks. Some of the reasons for this are purely practical- some tasks require that pupils share resources (practical or computing equipment), some tasks require more than one person to complete them, but some of the reasons stem from a belief that collaboration has particular advantages for supporting learning. This reflects a change in attitude to collaborative group student learning. Drawbacks in such arrangements include the logistical problems of setting up groups and supporting them and the assesssment issues involved in teasing out individual scores from combined endeavours. The educational benefits are now percieved to outweigh these drawbacks and much contemporary instructional design is targeted at group work. In particular computer assisted learning is being rethought. While a few years ago the lack of hardware which required students to share computers was taken to be a problem which interfered with the possibility of individual students benefiting from the tailored feedback which was the key benefit to be gained from a learning situation involving computers, there has beeen a rediscovery of the potential benefits of collaborative activity and much computer assisted learning has been redesigned as computer supported collaborative learning.

Collaborative learning in science

My research focus is to study the cognitive benefits children gain from learning in groups particularly in the context of recent curriculum moves towards investigative learning in science. This study requires a consideration of the particular processes by which the group interaction proceeds. The number of studies of groups working with computers has grown in recent years. For example, Webb (1989) conducted a number of studies investigating learning in small group settings, on mathematics and computer programming tests, where she found that certain individual domination of certain interaction processes (for example, helping) can lead to possitive learning gains at least for the helper. One key factor discussed in many studies is the different role which conceptual conflict plays with the differently constructed groups. Conflict as a stimulus for learning is a Piagetian idea. White and Fredriksen (1987) have suggested that revealing inconsistencies or conflicts in learners' different internal models of a topic under study could help to increase their understanding of science. When a child works with another on a problem situation, the consequences of the different models become apparent to each other, and the difference in their views can produce conflict which forces each child to restructure their position. Although some researchers have found that cognitive conflict like this improves the performance of the group (e.g. Howe, 1992), other studies have found that too much conflict can be counter

productive. Some other workers e.g. Harlen (1992) question conflict as a suitable technique to promote conceptual change among young children.

Gender effects

Underwood et al. (1992) found pupils from boy-girl pairs performed significantly worse during a computer-based language task than pupils from single-sex pairs. Some workers have suggested that these gender effects can be altered. For example, Barbieri and Light (1992) found gender effects with a computer-based treasure hunt task which were reversed when a more gender neutral version of the task, (involving bears searching honey rather than pirates seeking treasure) was presented (Littleton et al.,1992). Pozzi et al. (1993) suggest that their tasks (groupwork with computers of 9-12 yrs old pupils) using Logo and a database progam) had no gender bias and that was the reason that no differences were found between the behaviour of boys and girls on their mathematics learning. Although claiming that neither gender or ability measures directly effected learning, "interpersonal perceptions arising from these two factors were associated with different forms of group processes." They also looked at sociometric data about the participation within groups and characterised fragmented styles of working associated with cross gender antagonism. They conclude that "Implicit social marking in the classroom and the charcteristics of peer relationships in and out of the classroom may constantly undermine the conditions for successful groupwork."

Gender effects are particularly important when groups work on science related tasks. Johnson et al. (1985) investigated this topic and Petersen at al. (1991) reviewing their (and other related) findings concluded that "female subjects deferred to male partners in problem solving situations, were less active verbally, less influential, less task oriented, and more likely to agree with and praise group members than male subjects." Tolmie and Howe (1993) investigated gender differences in the expression of opinions of pupils engaged in investigative science tasks. The pupils, in male, female and mixed-sex pairs of 12-15 year-olds who were videotaped while they worked on a computer-based task which required them to predict the trajectories of falling objects. Tolmie and Howe comment on the markedly different interaction styles which each group displayed but noted that each type of group progressed equally in understanding. Carli (1993) in a study investigating influencing behaviour in mixed- and same-sex dyads with adults found that gender differences were larger in same-sex than in mixed-sex groups and that both sexes used more masculine interaction styles when trying to increase their influencing behaviour.

The studies

CCIS and CSCW

Two studies were conducted at the Open University which invvolved groupwork for science learning, the Conceptual Change in Science project and the Computer Supported Coperative Work in Physics in physics (CSCWP) project. The Conceptual Change in Science project (Scanlon, 93) used specially designed computer software to improve the science performance of a mixed group of thirteen year olds. The CSCW project (Whitelock et al.,93) investigated the ideal composition of a group so that cooperative work on a physics simulation with fifteen-year-old schoolchildren at the computer would produce most improvement on a task related to conservation of momentum.

The Conceptual Change in Science project considered how to improve the science understanding of a mixed group of thirty thirteen year olds using specially designed computer software to study Newtonian mechanics. Four scenarios (the *Rocket Skater*, the *Parachutist*, the *Speedboat*, and the *Supermarket*) were brought to life in simulations which combine with support materials to form an integrated teaching package which also includes 'real' practical experiments. The choices made about the contexts to be used in the scenarios involved much discussion. National and international surveys of science performance e.g NAEP or APU have repeatedly demonstrated that if the situations chosen to assess physics content are overtly "masculine" e.g involve building sites or racing tracks boys perform well whereas domestic situations produce better performance from girls. Pupils (29 children aged 12 -13 in a mixed ability class) were helped to form new concepts which they could use to interpret their experiences in mechanics, adopting a constructivist approach building on their prior

conceptions splitting their time between practical the computers. The class was divided into ten groups (chosen by the class teacher), nine triads and one pair. The groupwork consisted of seven weeks working in fixed triads. Before the main experiment the groups were operated for a two week trial period. which none of the mixed sex survived. The effectiveness of the curriculum was measured by comparing individual student performance on a pre and post test and we experienced some significant improvement in pupil performance (see Hennessy et al., in press). Gender did not appear as a relevant variable from the ANOVA, a surprise given the previous results from APU test items (Johnson and Murphy, 1986), but may be partly explained by the successful choice of contexts for the scenarios. Several groups of girls commented favorably on the scenarios. Some related their own past experiences on speedboats to the observations they made, in contrast to previous findings where girls tend to only draw on formal school experience when responding to science tasks. Also several observers did comment on the different behaviour of the m-m as opposed to f-f groups, with the girls' groups behaving more cooperatively. One vignette which illustrated strikingly the different group behaviour was that one group of boys unable to agree on a strategy decided to use two computers the girls group which they ousted tried to move another group of girls from their computer rather than challenging the boys. Also, in post experiment interviews, we found that many of the girls expressed a preference for conventional rather than computer practicals. Particular efforts were made to design scenarios which were equally appealing to both boys and girls, and our findings on conceptual change show no particular advantage or disadvantage for boys or girls groups. However, there were some observations from the project that the groups behaved differently and this is tune with related work by Whitelegg et al., 1992 on groups working on primary science investigations without a computer.

The Computer Supported Coperative Work in physics project investigated the construction of groups to facilitate cooperative work on a physics simulation. The task was to make some predictions about the be'~viour of a set of pucks using the Laws of Conservation of Momentum and Energy in a computer lation *Puckland*. Pupils were pretested, had access to the simulation where they were given time to check out their predictions and to experiment with any other situations which interested them before completing the problem solving exercises, then post tested. Sociocognitive conflict was expexted to improve the performance of the group (cf Howe,1992). Single gender pairs of 15 year old schoolchildren were formed by analysis of the performance on pre tests of eighty children. The performance of four types of pair were considered: boy/boy pairs with similar views of the physics concept, and girl/girl pairs with similar views and two further groups with differing views on the physics. All the groups increased their scores on the post test by at least 50%. The similar pairs rather than the different pairs improved the most. 'Girls similar' improved most of all (pecentage score increase from pre to post test) with boys similar coming next , with boys and girls different being equal third. On inspection, the girls similar had the worst scores on their pre tests however. It seems that girls were disadvantaged by their lack of practical experience of collisions, a finding which is in tune with previous work (see e.g. Johnson and Murphy, 1986). From this set of experiments, we were struck by the evidence for the productive behaviour of groups of girls who have similar views of the topic under investigation. This finding goes counter to the work described above on collaborative learning where the importance of sociocognitive conflict is stressed. Further detail of this work is available in Whitelock et al., 1993.

Shared Alternate Reality Kit

The third project using the Shared Alternate Reality Kit (SharedARK)invloved researchers from the Open University, Xerox PARC and Rank Xerox EuroPARC. The project involved adults working in mixed and single gender pairs at a simulation of the "running in the rain" problem (de Angelis,1987) where part of the task was that subjects needed to decide the precise problem to be solved. This deals with whether to run or walk in the rain without an umbrella. Running means spending less time in the rain. On the other hand, since you are running into some rain, you might end up wetter than if you had walked. This is a hard problem for a university student of mathematics or physics. ARK (Smith, 1992; Scanlon and Smith, 1988) is a system for creating interactive animated simulations. SharedARK, a distributed version of ARK, (Smith, 1992) supported an experiment with pairs of users communicating over a simulation from remote locations with an audio and video link. A user's screen enables them to see a portion of this plane and users can scroll over the two dimensional world of simulated ohysical objects. Because two users can scroll to different and arbitrary points on the plane, they may not see the same portion of the world. If their views overlap partially they have access to the same objects, and users can drag their rectangles into coincidence to work with the same objects or can

move them apart to work on seperate portions of the task. So, SharedARK, a prototype technology for allowing students to work together at a distance from each other was used to allow two users in seperate rooms with a workstation each to communicate through a high fidelity hands free audiolink with a camera monitor device called a videotunnel which enables eye contact. After an eight to ten minute introduction to the interface and the task when they are told that the object of the activity is for them to jointly agree when it is worth running in the rain, the subjects were given a microworld containing a rain cloud, a rain runner and a device to control simulation parameters such as the speed and the direction of the rain and the wetness of the runner. Subjects were invited to use the microworld to test their ideas and after 90 minutes they were asked to report on their findings. The evaluation technique involved collecting four synchronous video signals made up of what was displayed on the two video tunnel screens and the two simulation screens looked at by the subjects. This video protocol was analysed by relating utterances to both simulation events and eye contact. The utterances were categorised into those related to the interface, the task and those that had a social aspect. These uttereances were then assigned to subcategories called meta-level, specific and repair. Collecting these protocols, making transcripts and devising and applying a coding scheme to the transcripts was resource demanding but has resulted in a variety of useful findings related to multimedia distributed problem solving. Some features of the dialogue are described in Taylor et al., 93, and the type of augmented problem solving which was facilitated in Scanlon et al., 1993, but the main result of this experiment was the importance of eye contact through the videotunnel in establishing successful collaboration (Smith et al.,1989), and the creation by technology of a shared workspace which places subjects into a kind of enhanced proximity in which it is possible to be simultaneously side-by-side through the Shared ARK interface and face-to-face through the video tunnel.

In this study with several mixed pairs we were able to notice some gender effects. It was originaly assumed that since being face to face facilitates patterns of mutual gaze, subjects would be comfortable with this situation and this condition would lead to more productive problem solving. However both subjects who worked together well and subjects who were at times uncomfortable working through the videotunnel were seen. Male/female pairings found the negotiation of their problem solving more successful than male/male pairings. One possibility is that in the case of male/female couples, the videotunnel achieves a distancing effect but at the same time preserves the process of gaze negotiation. which enables subjects to relax with one another, increased social distance therefore proving facilitative. In the case of male/male pairs increased social distance may exacerabate latent communication difficulties, a situation they may find difficult to rectify due to lack of acceptable strategies when the only non verbal medium open to them is mutual gaze. With only four male/female pairings, three male/male pairings and one female/female pair, this is a small scale study which would be improved by collecting more female/female protocols with a similar set up to check out how the finding applies to more female/female groups.

Conclusion

Gender influences the ideal conditions for facilitating group work with computers in science. The CCIS project illustrated the importance of selecting real world contexts to minimise gender effects. The CSCW in physics project showed that girls work best together at computers in groups where their views of the topic are similar, boys work best in groups where there is sociocognitive conflict. The SharedARK project demonstrated the potential benefit of systems which could allow gaze negotation while preserving social distance and that this social distance could be a key factor in influencing the success of mixed gender groups. It is important that more studies are conducted to illuminate the influence of gender effects on the outcomes of science groupwork.

References

Barbieri, M. and Light, P.(1992) Interaction, gender and performance on a computer-based problem solving task. *Learning and Instruction*

De Angelis,E. (1987) Is it really worth running in the rain? ,*European Journal of Physics*, 8, 201 -202

Hennessy, S., Twigger, D., Byard, M., Driver, R., Draper, S., Hartley, R.,,Mohamed, R., O'Malley, C., O'Shea, T., and Scanlon, E. A classroom intervention using a computer-augmented curriculum for mechanics. *International Journal of Science Education* (In press)

Hennessy, S., Spensley, F., O'Malley, C., Bayard, M., Driver, R., Hartley, R., Mallen, C., Mohamed, R., O'Shea, T. and Scanlon, E. A direct manipulation microworld for vertical motion. In *Proceedings of the Fifth World Conference on Computers in Education* (W.C.C.E.90), Sydney, July 1990.

Johnson,S. and Murphy,P. (1986) Girls and Physics: reflections on APU survey findings, *APU Occasional Paper No 4., D.E.S.*
Harlen, W. (1992) Research and the development of science in the primary school. *International Journal of Science Education*, 14, 5,491-503
Howe, C., (1992) Learning through peer interaction *Presentation to the British Assocation for the Advancement of Science Meeting*, Southampton, August
Johnson, D. and Johnson, R. , Scott, L. and Ramolae, B. (1985) Effects of single sex and mixed sex coopertive interaction on science achievement and attitudes and cross handicap and cross sex relationship. *Journal of Research in Science Teaching*, 22,207-220
Littelton, K., Light, P., Joiner, R., Messer, D. and Barnes. P. (1992) Pairing and gender effects in children's computer-based learning *European Journal of Psychology of Education,7(4),311-324*
Pozzi, S., Healey, L and Hoyles C. (1993) When do ability and gender matter? *Social Development 2,3,223-241*
Petersen, R., Johnson, D. and Johnson, R. (1991) Effects of cooperative learning on percieved status of male and female pupils. *Journal of Social Psychology*, 131(5), 717-735
Scanlon, E., O'Shea. T ., Byard, M., Draper, S., Driver,R., Hennessy, S., Hartley, R., O'Malley,C., Mallen, C., Mohamed, G, Twigger, D. (1993) Promoting conceptual change in children learning mechanics In *Proceedings of the Fifteenth Annual Conference of the Cognitive Science Society*, Boulder, Colorado
Scanlon, E., and Smith, R.B. (1988) A rational reconstruction of a bubble chamber simulation using the alternate reality kit. *Computers and Education* , 12 (1), 199 - 207.
Scanlon,E., O'Shea, T., Smith,R., O'Malley, C. and Taylor, J. (1993) Running in the rain-can a shared simulation help to decide? *Physics Education, March*
Smith, R.(1992) A prototype technology for distance learning. In Scanlon, E. and O'Shea, T.(eds) *New directions in advanced educational technology* Springer Verlag
Smith, R., O'Shea, T., O'Malley, C., Scanlon, E., and Taylor, J. (1991) Preliminary experiments with a distributed, multimedia, problem solving environment. In: J. Bowers and S. Benford (Eds.), *Studies in Computer Supported Collaborative Work: Theory, Practice and Design.* Elsevier Science Publishers
Taylor,J.,O'Shea,T., O'Malley,C.,Scanlon, E.and Smith, R. (1991) Discourse and Harmony:preliminary findings in a case study of multi-media problem solving. *Proceedings of Conference on Problems of Support,Survival and Culture* , Amsterdam, April
Tolmie, A and Howe, C.(1993) Gender and Dialogue in Secondary School Physics. *Gender and Education* Vol 5 (2) 191-209
Underwood, G., McCaffrey, M.,and Underwood , J.(1990) Gender defferences in a cooperative computer based language task *Educational Researcher*, 32(1),44-49
Webb, N. (1989) Peer interaction and learning in small groups. *International Journal of Educational Research*, 13(6) 21-39
Whitelegg, E., Murphy, P., Scanlon, E. and Hodgson, B. (1992) Investigating collaboration in primary science classrooms: gender. *Proceedings of 6th Conference on Gender, Science, and Technology,* GASAT, October
Whitelock, D., Taylor, J, O'Shea, T., Scanlon, E.,.Clark, P., O'Malley, C., (1993) Collaborative working in physics using a computer simulation. *Paper presented at the ICTE conference, Boston, March* .
White, B.Y. and Federiksen, J.R. (1987) Causal model progressions as a foundation for intelligent learning environments Report No 6686, BBN Laboratories, Cambridge, MA.

A stand-by system for secondary school mathematics

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Abstract

A concept for a *stand-by system* to support the course of secondary school mathematics and its development is described. The system is supposed to assist students during their whole secondary education when they work at mathematics on their own. The structure of the system is defined by main functions (solve, exercise, represent, discussion, learning, advice) which refer to the objects (concepts, theorems, task types, procedures) and subfields of school mathematics. The realization of the system bases upon knowledge-based methods and conventional data (text) processing and integrates a series of harmonized and interlocked software tools (shells and a hypertext system) and subsystems for manipulating formulae, figures, and phrases.

Why a stand-by system is needed

Mathematics is a central subject of the secondary school education. Normally a teacher instructs mathematics at the class-room, the students participate and the students are also occupied with mathematics when they do their homework. Although there are many mathematical school-books and there is much educational software to support the learning of mathematics, it is not easy for a student to get qualified assistance when working at mathematics on his or her own.

Systematic reasons for that lie in the organization of the mathematical instruction and the currently existing learning media. Some features of the instruction are:

• The secondary mathematical education is a continuous course lasting for many years (e.g. for 9 years in Germany). The contents and the focus of the instruction are steadily changing within short spaces of time. Students acquire a variety of knowledge elements and skills which are tightly linked up with each other.

• Teachers have free scope when organizing their instruction. There are of course the general contents fixed by directions of the Ministry of Education (like (Richtlinien 1981, 1984) in Germany), but a teacher is free in his or her didactic and methodic decisions. Those refer e.g. to the approach to a new subject-matter, to the focusing, to the sequencing, to the example material, to the used methods, and to the evaluation criteria. So the lessons of different teachers are usually very different.

Currently existing learning media are essentially one-sided even if they are of high quality. The one-sidedness may consist e.g. in a narrow subject-matter, in a rigid teaching strategy, in the teaching method chosen (e.g. tutorial, exercises, simulation), or in a limited accessibility to the elements of the material. There is no learning medium which may be used with the subject of the whole school mathematics for various purposes over many years.

As an alternative to the currently existing learning sources a *stand-by system* for secondary school mathematics is here suggested: It is defined as a many-sided, coherent, and extensive software system which is able to support students during their whole secondary school education when they work at mathematics on their own (Schmidt 1993).

Three motivational aspects to design and develop such a system are (1) the potential of computer-based learning systems, (2) the compensation of the weaknesses of mathematical education, and (3) the strengthening of a student's own learning initiative and the reduction of the dependence on the school and on the teachers.

Rough characterization of the stand-by system

Organization of the system. The main structural elements of the suggested stand-by system are *objects* and *main functions* (see figure 1). The mathematical material, the knowledge elements and the skills group round the

objects of school mathematics: *concepts*, *theorems*, *procedures*, *task types*, and *subfields*. The system includes a series of *main functions* which may be utilized by students: The *solving* of any tasks, the *exercise* of any objects, the *discussion* of mathematical contents in connection with the objects of mathematics, and the *representation* of mathematical subjects. There are the additional main functions *learn* and *advice* which are a subject of future investigations.

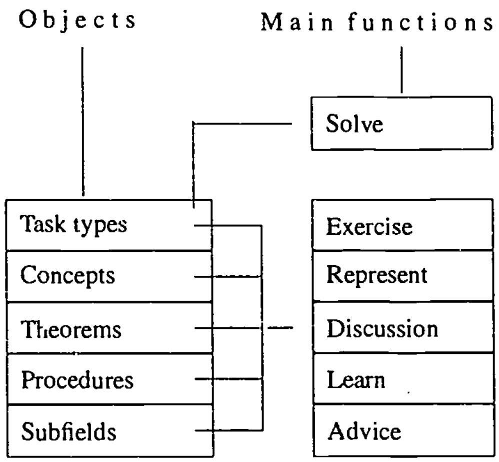

Figure 1: Structure of the stand-by system

Realization. The realizations of the main functions *solve*, *exercise*, and *discussion* rely on shells. The shells are based on a uniform knowledge-based language. The units of the language are sets. There are among other things *parameter sets* to collect variables, *rule sets* to specify procedural units, *calculation sets* to specify mathematical problems and their solutions, *action tree (graph) sets* to specify sequences of actions which control a complete process, *pattern sets* to specify phrase patterns, and *figure sets* to specify lettered figures. Programs which realize the functions *solve*, *exercise*, and *discussion* essentially rely upon the specification of a series of such sets. The realization of the main function *represent* bases upon a hypertext system. Those tools utilize subsystems referring to the processing of formulae, phrases, and figures. - The design of the shell or language is influenced by work in connection with expert systems, shells and knowledge engineering environments, above all MYCIN (Buchanan & Shortliffe 1984), OPS5 (Brown et al. 1985), and LOOPS (Bobrow & Stefik 1983).

Main function *solve*

The main function *solve* serves the purpose to solve the mathematical school tasks and to present the solution path with a varying degree of detailedness.

The realization of the main function *solve* currently concentrates on formally defined problems which are solved by numerical or formula manipulation methods and on text (word) problems which may be reduced to a formally defined problem by setting up one or more mathematical equations. Other problem categories like mathematical proofs and geometrical constructions are the subject of future investigations.

The solution of a word problem requires the capability of understanding natural language. The extraction of the relevant known and unknown quantities constitutes the main difficulty with the automatic solution of mathematical word problems. - The text problems will be semiautomatically solved by the stand-by system using the *dialogue method*, i.e. the programs determine the relevant known and unknown quantities of the task by a dialogue with the user so that the programs do not need natural language processing. The procedure of the dialogue method corresponds to the procedure of expert systems which also hold a dialogue to assemble the material for the description of a given situation (see e.g. (Buchanan & Shortliffe 1984, Waterman 1986)).

Two extensive prototypical programs dealing with *motion tasks* and *trigonometric word problems* demonstrated that very workable and reliable solution programs may be developed on the basis of the dialogue method (Ebenau & Leuchtenberg 1987, Becker & Köln 1990). For further details see (Schmidt 1986, 1993, 1994a).

Computer-based solution programs for mathematical problems may be useful both for students in their everyday learning routine and for the stand-by system to adapt the system to the special situation and needs of the students.

Main function *exercise*

The main function *exercise* supplies programs for exercising tasks of a task type, concepts, theorems, procedures, and subfields.

The realization of the main function *exercise* currently concentrates on the following task types: On formally defined problems which are solved by formula manipulation methods and on text (word) problems which may be reduced to a formally defined problem by setting up one or more mathematical equations.

The mathematical word problems which are regarded may be subdivided with respect to instructional objectives and to occurring components and their monitoring into three groups:

1. The first group contains problems which are reduced to equations or formulae of an application domain. Examples are the motion tasks or problems dealing with principal and interest.

2. The second group contains problems for which initially a geometrical figure is drawn, before any equations are set up. Examples are the trigonometric tasks and geometrical extreme value problems.

3. The third group contains problems which are reduced to an abstract system of equations. Examples are the distribution tasks.

Typical phases which appear in the solution paths of the above mentioned tasks are *(i)* the designation of variables, *(ii)* initial equations to mathematically model the task situation, *(iii)* formula manipulating and numerical calculations, *(iv)* figures with lettering to represent a geometric task situation, and *(v)* phrases to state the results of the solved problem. The phases may be introduced by headlines. - The wide majority of the mathematical word problems solved in the course of the secondary school education do not need more than those components to generate a complete path of solution.

The designed exercise shell allows to develop exercise programs with the following characteristics:

- Flexible choice from various exercise units.
- A user enters his or her solution path like he or she would do in the exercise-book: There is an empty window of the screen. Many variations of correct solution paths are admitted.
- The monitoring of a user's solution has the goal that a user finds the solution on his own or gets the opportunity to detect and correct errors by himself. A sequence of hints getting more and more detailed is provided when incorrect solution components are detected or a user requests help.
- The generation of only partial solution paths is supported.

A prototype of the exercise shell was implemented and a knowledge base dealing with distribution tasks was developed (Groß 1990). For further details see (Schmidt 1985, 1993, 1994b).

Main function *discussion*

The main function *discussion* serves the purpose that a user may occupy himself or herself with a mathematical subject on the basis of pre-stored questions. The word *discussion* is to express that the subject of the discussion is didactically analyzed as to the contents (i.e *discussed*) and that the elements and the results of the analysis are accessible to a user.

The current approach to the discussion of mathematical subjects may be outlined as follows: (1) A collection of questions is established for a clearly defined subject. The collection formulates the essential aspects of the subject in form of questions. The questions may be grouped and sequenced according to several criteria. (2) The wording of the questions is free, but the restricted possibilities of analyzing answers have to be taken into consideration. More complex answers may consists of any mathematical expressions or of simple phrases using natural language. To flexibly react to a user's answer the system is provided with a series of possibilities. (3) The course of a session is controlled by a mixed initiative.

Discussion programs may be among others used to intensively exercise the setting up of initial equations to mathematically model a word problem situation. See (Schmidt 1993) for an example in the field of calculus.

Main function *represent*

The main function *represent* serves the purpose to represent the subject-matter of school mathematics in a way that a student finds the material which he or she noted during the lessons also within the representation. That means

e.g.: There are the various didactic approaches to a subject described, there are detailed presentations of examples referring to task types, theorems and concepts. Logical connections and lines of reasoning are presented with full details.

The information referring to an object or to a subfield is structured using a set of recurring aspects like introduction, description, examples, classification, applications, foreknowledge tree, semantic net with the current object in the center, and hints.

The realization of the main function *represent* bases upon a hypertext system. A prototype of the hypertext system was developed by Klotz (Klotz 1992).

Outlook

At present no coherent software system corresponding to the concept exists, but a major number of prototypical programs were developed and more or less tested with students. The development of a workable and coherent system - called SCHUMA - is intended and it recently started.

The first phase comprises the (partial) implementation of the tools (solution shell, exercise shell, discussion shell, and hypertext system) and the implementation of the subsystems (formula manipulation, figures, natural language). Having got the tools and subsystems a workable and coherent system for the subfield of algebra (student ages 13 - 16) will be incrementally specified by generating knowledge bases and material representations. The start on the subfield of algebra suggests itself because it is a central subfield of school mathematics and the other subfields build up on the algebra.

In addition to the implementation, the main functions *learn* and *advice* will be conceptualized. In accordance with the destination of the stand-by system the main function *learn* above all refers to the learning of past (already taught) material and to the subjects of the current instruction. The main function *advice* is to assure that users get the assistance they want and need and that they fully take advantage of the opportunities of the whole system. The hints and recommendations will refer as well to the formal use of the system as to the learning and comprehension of mathematics.

The second phase comprises the test and evaluation of the coherent algebra system. If it proves to be successful in supporting the learning of mathematics and if it is well accepted and readily used with pleasure by students, the third step will be to extend the system so that the other subfields of school mathematics are covered.

To sum up: The notion of a *stand-by system* was defined. A possible structure of such a system was suggested and the realization of that system was roughly described. The development of the system SCHUMA and its test will be incremental over a longer space of time.

References

Becker, B. & Köln, H.-J. (1990). TrigEx - Ein System zur halbautomatischen Erkennung trigonometrischer Text-und Extremwertaufgaben. Institut für Informatik, Universität Bonn, Bonn, Germany. Diplomarbeit.

Bobrow, D.G. & Stefik, M. (1983).The LOOPS Manual. Xerox-Corporation.

Brownston, L., Farrell, R., Kant, E. & Martin, N. (1985). Programming Expert Systems in OPS5. Reading, Mass.: Addison-Wesley Publishing Company.

Buchanan, B.G. & Shortliffe, E.H. (Eds.) (1984). Rule-Based Expert Systems. Reading, Mass.: Addison-Wesley Publishing Company.

Ebenau, B. & Leuchtenberg, P. (1987). Ein Dialogsystem zur Lösung mathematischer Textaufgaben (Bewegungsaufgaben) in OPS5. Institut für Informatik, Universität Bonn, Bonn, Germany. Diplomarbeit.

Groß, R. (1990). Eine Shell zum Erstellen von Übungsprogrammen für mathematische Textaufgaben, die auf Gleichungssysteme führen. Institut für Informatik, Universität Bonn, Bonn, Germany. Diplomarbeit.

Klotz, U. (1992). Ein Hypertextsystem für Schulmathematik. Institut für Informatik, Universität Bonn, Bonn, Germany. Diplomarbeit.

Richtlinien für die gymnasiale Oberstufe in Nordrhein- Westfalen, Mathematik. Greven Verlag, Köln. 1981

Richtlinien (vorläufige) für das Gymnasium - Sekundarstufe I in Nordrhein-Westfalen, Mathematik. Greven Verlag, Köln. 1984

Schmidt, P. (1985). Teaching Mathematical Story Problems. Proceedings of 4th World Conference on Computers in Education (WCCE '85), pp. 389-392. July/ Aug. 1985, Norfolk, VA, USA. Participants Edition. Amsterdam: North-Holland.

Schmidt, P. (1986). Semiautomatic Solution of Mathematical Text (Word) Problems by the Tree-of-Questions Method. Proceedings of 24. Annual Conference of AEDS, pp. 276-279. April 1986, New Orleans, USA.

Schmidt, P. (1993). SCHUMA - Ein Stand-by System für den Ausbildungsgang der Schulmathematik. Institut für Informatik, Universität Bonn, Bonn, Germany. Report. 330 pages.

Schmidt, P. (1994a). The dialogue method to solve mathematical text (word) problems. (Submitted for journal publication.)

Schmidt, P. (1994b). A shell to develop knowledge-based exercise programs for mathematical text (word) problems. (Submitted for journal publication.)

Waterman, D.A. (1986). A Guide to Expert Systems. Reading, Mass.: Addison-Wesley Publishing Company.

An Alternative Precalculus Curriculum

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Abstract: A novel curriculum at the precalculus level has been developed at the National Technical Institute for the Deaf in response to powerful forces for change in mathematics education. The curriculum serves the dual purpose of preparing students for higher mathematical study and for the workplace, while taking advantage of the instructional power of graphing calculator technology. Fundamental differences from the traditional precalculus curriculum are analyzed, with examples.

The current technological revolution is at least as sweeping in its impact on the teaching and everyday practice of mathematics as that marked by the introduction of pencils and inexpensive paper some 500 years ago. The pace of change of today's revolution is more rapid -- happening over decades and sub-decades rather than over generations -- and is continuing, with no end in sight. We have witnessed in our lifetimes a dramatic drop in the *price* of practical computation. Just fifteen years ago a full range of electronic calculation, including evaluation of "scientific" functions, became widely affordable in educational, business and scientific circles at a price of about $500 per station. Today, such power is available in hand-held form for under $10.

This trivialization of the expense of electronic calculation has been accompanied by an expansion in the conception of what sort of computational power could and should be placed on the general marketplace for consumption by the public. Single-result calculations are no longer enough. Hand-held calculators on the market today at popular under-$100 prices allow storage of and pseudo-algebraic calculation with numerous values in named memories, and in fact storage of and calculation with *arrays* of numbers. These devices also allow creation and manipulation of sophisticated and illuminating graphic displays. Furthermore, capability is provided to enter user-generated programs of considerable sophistication. An additional startling capability of this new generation of computational tools is the ability to pass data, programs and generated graphic displays from one holder to another, or to pass them into (and out of) larger electronic networks.

Meanwhile, "high-end" computational tools have been developed that rapidly perform much more sophisticated calculations, including the types of symbolic manipulation that have occupied much of the working time of professional scientists, mathematicians and technicians over the last several centuries. This capability is also moving rapidly downward in price, being provided "free" (as part of the system software) with the newest generation of off-the-shelf computers. We should be able in a few years to purchase at neighborhood stores convenient devices that will allow us to enter literal expressions to be expanded, simplified, factored, or otherwise usefully manipulated (among other, as yet not fully apprehended, capabilities these devices will possess).

This proliferation of computing power has posed (and continues to pose) a tremendous challenge to our conception of what mathematical understandings and what computational skills should be the focus of the mathematics curriculum in our schools. Just as 500 years ago it was gradually found possible to introduce to the general student body concepts that formerly were addressable only in rarefied academic settings, and desirable to teach the manipulations newly possible with the aid of pencil and paper while ceasing to demand development of practical skill in the use of older technology (e.g. counting boards), so today are we recognizing that more sophisticated mathematical concepts can be introduced with success into the elementary and secondary curricula, and that attainment of a high degree of proficiency with pencil-and-paper computation may not be a worthy general goal. Students need to have some way to learn to "drive" the powerful new tools they will be expected to be able to use in the workplace, and if the mathematics curriculum does not address this need mathematics education risks becoming irrelevant.

The rapid and continuing pace of technological change has not, however, allowed for development of a general consensus with regard to this issue. We are instead witnessing a profound ferment in educational circles, as enthusiastic educators search for ways to make effective use of the new technology and as bold experimentation is tempered by the forces of conservatism, including educational administrators, parents and members of the larger society, who (understandably) feel their own command of mathematical understanding challenged by change.

To guide the evolution that must take place, larger insights into the process of change and ways of harnessing the new possibilities will be essential. One such insight may be that a large part of the evolution taking place today is a change in the role of the individual performing calculations from that of a laborer to that of a *supervisor*. No longer is sheer output of "brute-force" computation or calculation valuable in itself. Instead, what is important in performing a significant calculation is analysis of the task at hand, assembly of appropriate resources and their assignment in appropriate ways, anticipation and avoidance of potential pitfalls, intervention as needed to facilitate the work flow, validation of the quality of the output, and packaging and delivery of the results achieved. The understandings that need to be developed to equip students for this complex role, and the training necessary to develop such expertise, must be the primary focus of our educational efforts. Of course, it is difficult to be a good supervisor without having oneself spent some "time on the line", and a supervisor must be capable of "filling in" as needed in a pinch, so that it can be seen that total elimination of the learning by students of basic computational skills is not appropriate. However, a steady focus must be maintained on appropriate allocation of computational resources and on knowing how to make the most effective use of resources at hand.

The conventional mathematics curriculum is being challenged at all levels, but perhaps most severely at the juncture between the secondary schools and college, which is where calculus is traditionally placed. Calculus has been seen as the first course appropriate to study of advanced mathematics, requisite to formal study in all technical areas, and has been the expected primary math course taken during the first year or two of college. To meet this expectation, a variety of "precalculus" courses and course sequences have been developed, both at the high-school and college level, in an effort to prepare students for the rigors to be met when they encounter a formal calculus course.

As a result of the mathematics curriculum reform movement in recent years, however, there has occurred much discussion among educators regarding what a calculus course should appropriately consist of, at what level the fundamental concepts of calculus should be introduced to students, and whether calculus itself is the appropriate topic for a first experience of formal instruction in mathematics. Whatever resolution of these issues may result, it will remain true that there will be a need for prior courses at either the secondary or college level that develop skills and understandings that will support such formal study. In light of the changing technological environment discussed above, there would seem to be little doubt that such preparatory courses should aim to take as wide a view as possible of what the study of mathematics consists of and go well beyond the mere goal of providing students with some competency in the standard, traditional computational techniques that are so rapidly being automated. In particular, the standard "College Algebra and Trigonometry" curriculum that is reflected in so many of the mathematics textbooks that have been published over the last several decades would seem to be a relatively poor preparation for advanced work today.

At the National Technical Institute for the Deaf we have attempted to develop curriculum at the precalculus level that seizes on the possibilities offered by new technology to develop awareness in students of the sort of "supervisory" skills that they are likely to be called on to demonstrate in further mathematical study and later on the job, while still assisting students to achieve a degree of personal competence in numeric and algebraic calculation in various modes, including the use of pencil and paper. Specifically, we have developed a three-quarter sequence of courses titled Advanced Math 1, Advanced Math 2 and Concepts of Calculus that serve as a strong bridge to a standard Calculus 1 course, as well as to a variety of other advanced mathematical course work. These courses make integral use of the capabilities of a graphing calculator (we are moving to the Texas Instruments TI-82). It is the purpose of this paper to describe the content and structure of this course sequence and to indicate some of the instructional "threads" running through the work that distinguish these courses from standard precalculus treatments.

One of the threads running consistently through this curriculum is attention to concerns of notation. Levels of formality of mathematical notation range from loose, conversational communication through the semi-formality of standard mathematical notation to the complete formality demanded by calculator or computer input. Just as in the case of spoken and written communication, awareness and control of formality level is critical, and gaining such awareness and control is an important educational objective. The rich syntactical possibilities offered by the TI-82 provide an excellent domain within which students can learn to appreciate this point. Puzzling over why certain mathematical expressions on paper cannot just

be entered "as is" into the calculator throws new light on what is really shown and what is *understood by convention* in standard mathematical notation. Study of equivalent legal (though possibly nonstandard) calculator expressions, as well as study of apparently-but-not equivalent expressions, can be extremely revelatory of the meaning that must be perceived *through* whatever notation is being employed.

In non-calculator work, of course, movement toward increased formality (e.g. careful use of parentheses) has always been the key to achieving correct results in increasingly complex algebraic and numeric computations. Work demanding practice in producing such formal presentations must be part of any course at this level. However, another level of formality can be added by transferring some calculations entirely to the calculator display screen and requiring students to report (i.e. write down -- though print capability may become available soon) the resulting "window display" in its entirety. Doing so, and comparing alternate window displays leading to equivalent results, usefully changes the focus of discussion from the *answer* to the ***process***. Also, study of window displays can lead to development of a good working *style*, such as the use of variables (constants stored in calculator or computer memory) in place of directly entered numeric constants.

Central to the process of studying mathematics in a technological environment is the question of appropriate "division of labor". Which calculations are appropriately performed with the aid of a calculator, which with a bit of scratch work on paper, and which should be done mentally? The answers will vary from individual to individual, of course, but it is likely to be found that students a) will initially tend to use a calculator to perform calculations that an experienced person would perform mentally with confidence, and b) will tend to use paper and pencil to perform (imprecisely) calculations that really should be performed with a calculator. Furthermore, students typically need to learn to efficiently *propagate* calculated results by storing and recalling them rather than reentering them (imprecisely and possibly incorrectly). Development of a mature appreciation regarding this point and acquisition of a more appropriate set of habits is another major focus of the NTID Advanced Math sequence.

More than in the past, considerations of numeric *precision* and the occurrence of round-off error must be studied when calculators or computers are being used, and a certain amount of attention to these issues has been incorporated into the Advanced Math sequence as well. Both numeric and graphical artifacts -- and downright wrong answers -- produced by the calculator are held up for students to examine and account for, and occasions when it is possible to "fool" the calculator are explored. The basic point to be made is that a calculator must be regarded as a strong but not really intelligent member of a *team*, and is in constant need of "watching".

Regular use is made in the curriculum of very large and very small (and also very awkward) numbers -- when calculations are being performed by calculator there is no need to restrict examples and problems to those involving "convenient" values. Naive student notions of scale are particularly challenged in graphical work, for example by assigning the problem of graphing the equation $y = -0.003x + 597$. To help further break the common student habit of thought of "one square equals one unit", attention is paid to developing the skill of sketching graphs (as viewed in the calculator window) onto ***plain*** paper rather than onto graph paper, with the student adding such details as the labelling of axes and the coordinates of intercepts or other significant points. An attempt is made to develop a feeling for *shape* and apprehension and communication of critical topological details associated with a graph. Deciding whether to use graph paper at all when working with a problem is another important discrimination to be learned. The advent of inexpensive graphing software (and the capability to print out attractive computer-generated graphs on paper at will) is likely to severely reduce the general use of graph paper in the schools and the workplace!

The fundamental notion of a function and acquaintance with special properties of various standard "elementary" functions must of course represent an integral part of the content of any course at the precalculus level. A "function box" model is used extensively throughout the Advanced Math sequence, allowing visual representation of such concepts as function inverses and composition. When this is combined with the capabilities of the TI-82 to calculate and graph function compositions and inverses, a powerful environment for the study of these concepts is created. In addition to standard algebraic and exponential functions, together with absolute value, the "floor" and "ceiling" (greatest- and least-integer) functions are introduced to challenge naive notions of continuity. Composition and combination of simple functions with the TI-82 can produce highly interesting graphs, worth exploring in detail.

Related to the above concepts are the ideas of domain and range, always difficult for students to apprehend. These concepts are thoroughly and repeatedly investigated throughout the curriculum. The ability to trace graphs across the calculator screen (with the calculator obligingly refusing to display output when it is mathematically unavailable) is helpful here, as well as the diagnostic reporting of input errors by the calculator when performing function evaluations.

The circular functions are introduced formally, and their properties explored, by means of the *wrapping* function, with no explicit mention of angle. Careful attention is paid to scaling with submultiples of π. For many students this is the first time when precise calculation with simple fractions becomes *critical* -- decimal approximations won't do, the calculator is likely to be more of a hindrance than a help, and the exact fractional algorithms *must* be mastered. Geometry and algebra combine at this point to allow development of exact expressions for the sine and cosine of "special values" of the argument. As students learn to appreciate the point of being abie to provide an *exact* expression, pattern recognition is shown to be sometimes superior to (and at least a worthy partner of) blind computation.

The second quarter of the Advanced Math sequence represents an extended exploration of linear structures. Matrices are introduced and their properties and applications (including geometric transformations in the plane) are explored with the TI-82. A powerful isomorphism is observed between the complex numbers and the class of 2x2 matrices that represent combinations of dilations and rotations, which leads in a natural way to the idea of trigonometric representation of complex numbers and to a transparent development of the addition formulas for the sine and cosine and all of the trigonometrical identities that follow. Extensive work with transformations of formulas and identities, bolstered by direct supporting computations with the TI-82, extend the pattern-recognition skills developed in the first course in the sequence in preparation for the more formal, symbolic work to come in later courses. The representation of complex numbers by 2x2 matrices allows direct calculations with them to be performed on the TI-82 (and TI-81), and the opportunity is taken to go well beyond the trivial computations in complex arithmetic that traditional introductory treatments are limited to.

The third quarter of the Advanced Math sequence addresses topics that in one way or other involve the notion of limit. The first unit deals with sequences, playing back and forth between iterative and recursive processes. Extensive calculator work is incorporated in order to develop a feeling for the *meaning* of limit, and careful attention is paid to development of clear notation and language for describing arbitrary largeness and arbitrary closeness. The second unit moves to consideration of limits involving functions of a real variable, and begins development of a formal appreciation of the idea of continuity. The final section of this course introduces the idea of the derivative and explores its graphical meaning and various practical applications, as well as the opportunity to explore exponential functions and the special number e.

Students pursuing some of the technical associate-level degrees offered by NTID are required by their programs to complete the first two quarters of the Advanced Math sequence. Others take all three courses in order to satisfy concerns of accrediting bodies that programs include attention to calculus as a discipline. Yet other students use this sequence as a springboard to follow-up study of a rigorous calculus sequence in another college at RIT. In any case, students have reported the wide sweep of this course sequence and the attention given to newly-relevant educational concerns to be useful preparation for subsequent work.

TABLE 1. Partial Outline of Content in the NTID Advanced Mathematics Curriculum

ADVANCED MATH 1

Unit A .	1.	Introduction to the TI-8x calculator
	2.	The absolute value function; using menus; working with π
	3.	Using calculator variables; entering algebraic expressions
	4.	Formulas; units in calculations; storing formulas in memory
	5, 6.	Linear functions and graphs; slope and intercepts; scaling; tracing graphs
	7, 8.	Incidence between points and lines; slope rations; graphing absolute value functions
	9.	Graphical solution of systems of equations; graphs with parameters; shifting
	10.	The general quadratic equation; graphing parabolas; completing the square
	11.	Graphical solution of quadratic equations; the quadratic formula; fixed points

TABLE 2. Sample Homework Problems from the NTID Advanced Mathematics Curriculum

Adv1 A1-2. a) Use your TI-8x calculator to calculate `37(7928 - 1922)` by just entering this expression into the calculator, without using the x key.

b) Show that the window display `37*7928 - 37*1922` produces the same result.

c) Write another, different window display that will calculate the value of the expression in a) without using the x key.

Adv1 A2-1. a) Use your TI-8x to evaluate the expression $|3(1.3) - 4|$:

WINDOW DISPLAY: RESULT:

b) What result do you get if you change 1.3 to 1.4 in the above expression? What result do you get for 1.32 ?

c) Is it possible to change the 1.3 in the above expression to some number so that the result is exactly 0 ? EXPLAIN!

Adv1 A3-7. a) Store the value 47 in memory P, and then calculate the value of the following expression:

$$(219P + 93) - 3(73P + 64)$$

b) Change the value stored in memory P to -121.3 and recalculate the value of the expression in part a). EXPLAIN your results!

c) Write a different expression containing the variable P that will always have the same value, no matter what value is assigned to P.

Adv1 A5-4. The function $y = -0.003x + 597$ is a linear function. What is the DOMAIN of this function? What is the RANGE?

Adv1 A7-3. a) Use your TI-8x to show that the point (20,23) lies on the line $3147x - 2737y = -11$.

b) A point with **integer** coefficients, like (20,23), is called a **lattice point**. The line in a) passes through many lattice points. Find the coordinates of another lattice point that lies on this line.

c) CHALLENGER: Write the equation of a straight line that passes through the origin, but does not pass through any other lattice point.

Adv2 A6-2. a) Given that $A = \begin{matrix} 11 & -5 \\ -15 & 7 \end{matrix}$, $A^{-1} =$

b) If $AV = \begin{matrix} 67 \\ 83 \end{matrix}$ then $V =$ HINT: Multiply by A^{-1}

Adv2 A8-4. Given that $w = 20 + 21j$ and $z = 35 - 12j$,

a) Find $|w|$ and $|z|$.

b) Find $|wz|$ without calculating wz !

"Instructional Engineering" Applied to the Teaching of Mathematics/Science with Technology

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Abstract: The teaching of mathematics/science with technology may be improved by employing methods and techniques of instructional design. There are proven methods and techniques for designing instruction to effectively teach an intellectual skill like the problem solving of mathematics/science. A description of some of the most fundamental methods and techniques of instructional design to teach an intellectual skill and how they would apply teaching mathematics/science with technology are given in this paper. Assessment and mode of delivery for instruction are explained as essential parts of teaching mathematics/science with technology.

The author is not sure if the term "instructional engineering" has been used before but he uses it here to point out that there are methods and techniques for the preparation of instruction that can make the instruction more effective. Those methods and techniques can be applied to the preparation of instruction in mathematics/science courses taught partially or completely with technology. Few instructors in higher education have the opportunity or the time to study in the field of education. Therefore, it may be useful for them to consider some of the proven findings from educational research that relate to teaching topics such as mathematics/science. Also, few secondary or elementary education majors receive adequate exposure to the use of technology as an aid to teaching. Perhaps some of the topics discussed below can prove useful to both groups. The author can attest to the usefulness of applying methods and techniques from education to the teaching of mathematics/science with technology.

It has been shown time and time again that well designed instruction leads to a higher probability of learning by the student than does poorly designed instruction (Gagne, 1988). It is therefore desirable to understand some of the best known instructional design methods and techniques that apply to teaching mathematics/science with technology.

Problem Solving in Mathematics/Science

A mathematics/science course takes on the characteristics of a course in problem solving. For example, software engineering is a subdiscipline of computer science that offers methods and techniques to develop and maintain quality software to solve problems (Mayrhauser, 1990). The problems considered are, in many cases, the type that can be explained/solved through the use of a computer driven system. Such a system might include: an instructor with computer related training, software that has been evaluated by the instructor, classroom presentations that include the use of technology, use of networking to access materials from other locations, etc. In any case, we are solving problems and implementing their solutions with technology. In order to teach a student to "do" problem solving, we must teach him/her a specialized form of an intellectual skill. We are teaching an intellectual skill when we teach problem solving. This is true if we use technology or not. So, to use technology to teach mathematics/science effectively, we must apply the technology to methods of instruction that are known to be effective in teaching mathematics/science problem solving. We cannot simply assume that the introduction of technology into a mathematics/science course makes the teaching more effective or learning more

probable.

Within a college of education or a department of education it would be said that if we are teaching problem solving, we are trying to teach an intellectual skill. In order to learn an intellectual skill, the student must acquire what is know as procedural knowledge (Anderson, 1985). Such learning contrasts with learning that something exists or has certain properties. The latter is verbal information. Procedural knowledge involves learning how (i.e. how to do) while learning verbal information means to learn that something exists or has certain characteristics.

A Look Ahead to Assessment and Evaluation

It is important to note, at this point, that when an intellectual skill is taught the methods used for assessment of student performance and evaluation of the instruction are prime concerns. Assessment of learning and evaluation of instruction are mentioned here since, although they occur after instruction has taken place, one must clearly understand what will be assessed and evaluated before effective instruction can be designed. In other words, we must know what we want at the end of the process before we start the process. Some instructors may mentally design tests before designing instruction and others may actually create the assessment and evaluation tools (i.e. tests) before instruction is designed. After assessment, if the students learned what was intended, the instruction can be evaluated as "good". Otherwise it should be redesigned and possibly redelivered.

If one wishes to know whether the student has learned an intellectual skill one must observe a category of performance. Criterion levels (i.e. performance levels) can be established at any point in instruction where it is necessary to obtain information as to the adequacy of an individual's performance (Glaser, 1963). Simply asking if the intellectual skill exists (i.e. does problem solving exist) or what its characteristics are would be insufficient. In other words, we must decide if we are teaching students that problem solving exists and what its characteristics are or if we are teaching them how to "do" problem solving. In this paper the author will assume that we wish to teach students to "do" problem solving with technology. We will return to assessment and evaluation but we can now proceed to designing instruction.

Designing Instruction

The purpose of instruction is to provide the events of instruction:

1. Gain attention
2. Inform learners of the learning objective
3. Reminding students of previously learned content
4. Clear and distinctive presentation
5. Guidance of learning
6. Eliciting performance
7. Providing feedback
8. Assessing the performance
9. Arranging variety of practice

(Gagne, 1988)

To an experienced teacher, it soon becomes apparent that the key events are 3, 4, and 5. When an intellectual skill like problem solving is to be taught: event 3 means we must stimulate the recall of previously learned intellectual skills, rules, and concepts; event 4 means we must display a statement describing the intellectual skill, with examples, and give emphasis to features of component concepts; event 5 means we must provide varied examples in varied contexts and give elaborations to furnish cues for the retrieval of the intellectual skill components in the future. We can apply this theory from education to instruction in mathematics or science. We need to review important background information and skills, to clearly explain what is to be learned and to help students through some examples of the type of performance they will be expected to exhibit without help at a later time during assessment. Let's take a closer look at events 3, 4, and 5.

Event 3 - Remind Learners of Previously Learned Content

It is critical that an instructor have a clear idea of what a student must know in order to enable the student to acquire the intellectual skill being taught. Put another way, an instructor must know what lower-level rules are

required to enable a student to develop higher-level rules (i.e. solutions) (Scandura, 1977). For example, an instructor must know that a student needs multiplication skills before trying to learn to do long division. These necessary "pre-learned" skills are called enabling prerequisite skills. For problem solving to be learned and retained, a student must enter the course with a long list of enabling prerequisite skills that have been mastered.

Instruction aimed at teaching an intellectual skill has less of a chance of success if the necessary enabling prerequisite skills have not been learned. Therefore the author recommends the use of some means to discover whether or not students have learned the necessary enabling prerequisite skills. This implies that the instructor has taken the time to list those skills and can assess the level of student performance of those skills. A good example of how to accomplish such an assessment of necessary enabling prerequisite skills is to give a pretest. Perhaps looking at previous grades or speaking to other instructors would be enough in some systems. If an instructor wishes to try to make sure that students have learned necessary enabling prerequisite skills needed to learn the skill that is the objective of his/her course, the instructor must be very organized.

An experienced instructor can list necessary prerequisite skills without much effort and usually in their order of dependence. An inexperienced faculty member may be required to put more effort into gaining such an understanding. It may be necessary to do learning task analysis. Learning task analysis is the process of 1) classifying learning outcomes according to types of learning and 2) determining, for a given outcome, the essential and supporting prerequisites that are involved (Briggs, 1977). When learning task analysis is done, there will be an obvious point at which the skills switch from being those previously learned to those that need to be learned. This is the point at which objectives for instruction in the present course can be clearly identified (i.e. what will be taught and how will students be evaluated). With such organization, what remains is to provide the events of instruction that will enable the students to acquire the desired intellectual skill.

Event 4 - Clear and Distinctive Presentation

Our instruction should include some clear examples of what we wish students to learn. We should also include some discussion about how what is to be learned is different from what has been learned along with any unique characteristics. This could be accomplished in a mathematics/science course by presenting and discussing how certain mathematics/science concepts are applied to a new or existing situation. In this case, situation means a clearly defined context. The presentation should include all of the points that will be important during assessment and evaluation.

Event 5 - Guidance of Learning

Students should be asked to "try out" their newly learned intellectual skill under the watchful eye of the instructor. The first time they perform what was to be learned should NOT be on an examination. In this step the instructor is a resource or helper and not an assessor. In a mathematics/science course, this could be done by letting students "do" problem solving on a real or imaginary, new or existing system. The key to this step is guidance. The instructor should not hold back information or rely on students to completely discover concepts and skills. There is no real value in surprises or a "mystical" image as an instructor. Both cause stress for students and stress can reduce the quality of performance and amount of retention.

Technology's Role

It should be clear to the reader that technology cannot replace planning or increase learning by itself. Simply introducing technology into a course or curriculum may even reduce the amount of learning or retention of the subject matter being taught. The question to ask is "Will the students learn more or perform more efficiently if technology is introduced into their lessons?" It may be necessary to do a little experimentation or background checking to see when and where technology has been used successfully to improve learning. It is surprising how few well done, documented examples of technology improving learning actually exist. It would be wise, especially for a new user of technology in the classroom, to use the following simple guide. Since much research has been done to prove that Gagne's events of instruction are helpful in designing and delivering instruction, try to use technology in a way that provides those events for the learners. A typical example would be using a drill and practice program on a computer to allow elementary school students a chance to review addition skills.

More About Assessment and Evaluation

Just to clearly explain the usage of the words assessment and evaluation in the context of this paper, assessment is done to measure learning and based on that assessment instruction is evaluated. After instruction has taken place, it is important that a proper method of assessment be used to determine whether the instruction was successful. To assess the success of instruction in an area like mathematics/science, one must employ a method that does not involve simply checking a list of answers against a key to arrive at grades. There must be a way for the student to perform using the newly learned intellectual skill. Then judgment must be employed to determine the quality of the performance. Since this judgment must be made on a complicated performance, in many cases, it is not a good idea to let an underqualified person make the judgment. The entire process can be undermined if assessment is not done carefully and correctly because an instructor should use the results of assessment to evaluate instruction. Instruction judged "poor" as a result of poor student performance during assessment should be redesigned. Therefore, the instructor must take great care to do unbiased assessment.

Assessing student performance in a mathematics/science course can be complicated and time consuming. Each student should have the opportunity to perform exactly what they were told they would have to perform. For these reasons, it is often the case that assessment is done in a style that is insufficient. Also, test conditions should be similar to practice conditions. If technology was used during instruction and practice, then it should be used during assessment.

Mode of Delivery

One more topic to consider is the mode of delivery of instruction that would be suited for a course in problem solving related to mathematics/science. The ideal case would be one-to-one instruction. This is hardly possible. So small group (3 to 8 students) instruction is often implemented. This is not always possible either but if it is a great deal of one-to-one interaction can take place. There is some loss of precision and flexibility. Discussion is easily promoted. Problem solving is a commonly adopted goal for discussion in small groups (Maier, 1963).

The worst choice of instructional mode for teaching an intellectual skill is the lecture mode. This conception of instruction runs contrary to the notion of mastery learning proposed by (Bloom, 1974, 1976). Bloom's mastery learning concept is the type of learning that must occur for a student to acquire an intellectual skill. Therefore it would be very beneficial to find a way to use technology to help accomplish more one-to-one instruction. If a student is to react one-to-one with a machine, great care must be taken to assure the quality of the session. Testing and preparation of the system by the instructor becomes critical.

Summary

We should not consider the design of course syllabi to be the design of instruction nor the design of education. There are proven methods and techniques we can employ to design, deliver, assess, and evaluate the teaching-learning process effectively. If we provide the events of instruction, in this case for teaching an intellectual skill, we are more likely to have our students acquire that skill than if we do not. Used wisely, technology can help provide the events of instruction. Experience can be useful in deciding what is to be taught as well as what should have already been learned but learning task analysis can be helpful. Assessment should be used to find out what students have learned and as feedback to the instructor to help evaluate the instruction. Using the proper type of assessment is very important. And finally, the mode in which we deliver instruction can be as critical as deciding what to teach. Technology can be a useful tool to implement whatever type of instruction we decide to implement.

References

Anderson, J.R. (1985). *Cognitive Psychology and Its Implications.* (2nd ed.). San Francisco: Freeman.
Bloom, B.S. (1974). *An Introduction to Mastery Learning Theory.* New York: Holt, Rinehart and Winston.
Bloom, B.S. (1976). *Human Characteristics and School Learning.* New York: McGraw-Hill.

Briggs, L.J. (1977). *Instructional Design: Principles and Applications.* Englewood Cliffs: Educational Technology Publications.

Gagne, R.M. (1988). *Principles of Instructional Design.* New York: Holt, Rinehart and Winston.

Glaser, R. (1963). *Instructional Techniques and the Measurement of Learning Outcomes:* Some Questions. American Psychologist, Vol. 18, 519-21.

Maier, N.R.F. (1963). *Problem-Solving Discussions and Conference.* New York: McGraw-Hill.

Mayrhauser, A. (1990). *Software Engineering.* San Diego: Academic Press.

Scandura, J.M. (1977). *Problem-Solving.* New York: Academic Press.

Issues in Interactive Multimedia Cross Platform Design and Implementation

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Abstract:

Atlas-plus™ is a large interactive multimedia program developed at the University of Michigan Medical School on the Macintosh environment using the authoring software Authorware Professional. Although all of the lessons in the software were originally designed for use at the Medical and Dental School level, some of the lessons are suitable for use with a wider audience.

In the fall of 1993, the nine introductory modules which cover the basic body systems:

* Cardiovascular
* Digestive
* Endocrine
* Integumentary (Skin)
* Muscular
* Nervous
* Respiratory
* Skeletal system and joints
* Urogenital

were transported to the PC Windows 3.1 platform for use by the advanced placement science classes at the high school,

The purpose of this paper is to document the cross platform design and implementation issues which arose when a large (90 Meg) sophisticated multimedia piece of software was transported from the Macintosh environment to the IBM PC Windows 3.1 platform for use by the high school students.

In the last four years, microcomputers have rapidly evolved from machines used primarily for business applications such as word processing, spreadsheets, or databases to sophisticated multimedia machines capable of integrating high resolution graphical images, animations, and digitized video. The graphical user interface, common for years on the Macintosh platform, has brought desktop publishing to the PC. It is common to see Macintosh and PC versions of the same application software. Local area networks readily allow PCs and Macintoshes to exchange files between machines. One no longer has to buy "all" Macintosh or PC for a computer lab.

Sophisticated authoring software is now available on both the Macintosh and PC platforms so that it is now possible to develop interactive tutorials on one platform and transfer them to another environment. This has led to an increased interest in the possibility of cross platform development of educational software.

The purpose of this paper is to share some of the problems and issues which had to be resolved when a team of designers and programmers at the Learning Resource Center at the University of Michigan Medical School transported a large, sophisticated interactive multimedia tutorial named Atlas-plus™ from the Macintosh environment to the PC platform for use in an advanced placement science class at the local high school.

Briggs, L.J. (1977). *Instructional Design: Principles and Applications.* Englewood Cliffs: Educational Technology Publications.

Gagne, R.M. (1988). *Principles of Instructional Design.* New York: Holt, Rinehart and Winston.

Glaser, R. (1963). *Instructional Techniques and the Measurement of Learning Outcomes:* Some Questions. American Psychologist, Vol. 18, 519-21.

Maier, N.R.F. (1963). *Problem-Solving Discussions and Conference.* New York: McGraw-Hill.

Mayrhauser, A. (1990). *Software Engineering.* San Diego: Academic Press.

Scandura, J.M. (1977). *Problem-Solving.* New York: Academic Press.

Issue #1: Hardware Considerations

On the Macintosh platform, hardware is more standardized than it is on the PC. Often one simply attaches the needed peripheral into the correct outlet at the back of the machine. The video and audio components are built into the system. The major differences between the various Macintosh machines lie in the speed of the microprocessor chip, the color video support, the amount of RAM and how many slots are available. 8 bit color video support is standard on the older machines and either 16 bit color or 24 bit color is found on all of the newer ones. With the 660AV, one does not even need a video capture board to capture QuickTime movies. It is easy to implement full-motion video with a laserdisc player using a two monitor system.

The opposite is true in the PC environment. It is critical to be familiar with the "target machine" as early as possible in the cross platform software transport process in order to make the necessary changes to the multimedia software before it is transported. PC hardware is a confusing menagerie of peripherals and cards manufactured by competing vendors. There is no "standard multimedia PC." Whether or not a sophisticated piece of interactive multimedia software will successfully run on a PC depends on how well several hardware components work together. One weak link such as a slow microprocessor or an inadequate video card can render the software unacceptable on a system. Three of the most critical multimedia components are microprocessor speed, the monitor configuration and the video graphics card. According to Poor (1993), it is very important to pay attention to a monitor's vertical and horizontal scan rate and its dot pitch. For the best results, one should aim for a monitor with the smallest dot pitch and the highest refresh rate, preferably non-interlaced. In order to run a sophisticated piece of interactive multimedia software one needs a PC which meets the MPC level 2 standards at miminum: a 486 microprocessor, 4M of RAM, a 160M hard disk drive, a double speed CD-ROM, a 16 bit sound card and VGA display capable of showing 65K colors at 640 X 480 resolution. (Perry, 1994,p. 19)

Another major issue exists at the school level. Frequently the interactive multimedia software, which is currently being developed and transported, will not run on existing PC machines because the computers are barely MPC1 compliant i.e. "16MHz 80386SX microprocessor, 2M of RAM, 30M hard disk drive, VGA adapter with 640 X 480 resolution at 16 colors, 8 bit sound card, MIDI In/Out/Thru connections and a CD-ROM drive with minimum transfer rate of 150K/sec." (Perry,1994,p.17) Our high school was enthusiastic about the possibility of integrating the Atlas-plus™ software into their curriculum, but the target PCs consisted of eighteen IBM PC Model 50Sx each with 4M of RAM, a 13 inch monitor and a 16 color VGA card. The hard disk drives were too small to store the entire software tutorial. The VGA graphics card was unable to show the high resolution graphics that were contained in the modules. The microprocessor was too slow to run the software or the QuickTime movies at an acceptable rate. Even after they upgraded their graphics card to a Windows graphics accelerator card, the software runs too slowly for the students to adequately use it. We are still working with them to develop modules which they can use.

Issue #2 Software Considerations

Although Authorware Professional has developed software versions for the Macintosh and PC platforms, the transport of the tutorial from the Macintosh to the PC environment was far from smooth. We had problems with the text transfer because the fonts selected during the initial development of the software were not later available on the PC platform. We spent a large amount of time changing the font of the text on every screen to Century Schoolbook after software transfer.

Modularity was also a critical issue. Even though the software consisted of nine modules, over time each individual module had continued to grow as more information was added. Several of the modules were very large (over 10 Mg) and the authoring software had difficulty converting them to the PC platform. We had to divide some of the modules into pieces and then reconstruct them on the PC side.

It is an important user interface concept in software design to let the end-user know where they are in "cyberspace" and what parts of the tutorial they have completed. This is frequently done using checks or buttons that turn black. We found that buttons which worked on the Macintosh side became non-operational or worked erratically on the PC side. Several times we had to resort to programming the buttons in order to force them to change colors.

Issue #3 Graphics File Transfer

Graphics files are not stored in the same formats on the PC and the Macintosh environments. We found that it was easiest to transport an existing graphics file to the PC platform when we converted the Macintosh PICT files within PhotoShop to indexed color, selected the 8 bit and system palette options and then

save the files as an IBM TIFF files. One needs to be aware, however, that although the TIFF format is a versatile graphical image format which can be readily used on a variety of computer systems, it is also "open ended format that is often modified by programmers. (Corrigan, 1994) Sometimes this results in a software application on the PC side not accepting a TIFF graphic file for import.

The incompatibility of the color palettes on the Macintosh and PC platform can lead to images having one color on the Macintosh and quite another on the PC. Jerram and Gosney et al (1994, p. 338) suggest that one solution may be to capture the standard VGA palette of PC to a TIFF file under Windows and transfer the palette to the Macintosh in order to create images in the Macintosh environment using colors from the PC VGA palette.

We experienced most of our difficulty when we tried to transfer the 16 bit and 24 bit graphical images. Sometimes the limitation was with the authoring software. Images which would look fine in PhotoShop would be totally unacceptable when imported into Authorware Professional.

Issue #4 Video Transfer

Full-motion video on the Macintosh environment using QuickTime movies is relatively easy to capture and place into a interactive multimedia tutorial. Using a capture board such as VideoSpigot, for example, one may quickly convert videotape sequences of muscle actions into digital movie clips. One is able to capture using either thousands of colors (16 bit color) or millions of colors (24 bit color).

Digital movies on the PC platform are still in their infancy, however. There are two methods of incorporating full-motion video into a multimedia application. One is to transport Macintosh QuickTime movies to the PC using the QuickTime movie converter. There are three issues which will hopefully be resolved as the medium developes in the future. One, the movie converter converts the Macintosh QuickTime movie to 8 bit color when it converts it for use on the PC platform. This results in the movies becoming rather blurry on the PC. One also loses the use of the movie controller on the PC side. This removes one of the most important assets of QuickTime movies -- user control of how they want to interact with the clip. The number of times that a movie plays has to be set-up in a button or programmed into the application. One is not able to edit the movies once they have been transported to the PC platform, either.

The second method is to use Microsoft Video for Windows. An important advantage of Microsoft Video for Windows is that one may capture and edit movie clips on the PC platform, but one must have an expensive video capture board to do so. The movies are not transportable to the Macintosh side, however.

Macromind Director movies are not recommended for transport to the PC environment. There are problems with layering when they are used in Authorware Professional on the PC.

Issue #5 Networks

Large interactive multimedia software which has many animations, high resolution graphics images, and digitized video tends to run too slowly when it is networked. It is preferable to press the software onto CD-ROM disk or run the application from a hard drive instead. If hard disk space is an issue, placing only the module needed for the specific lesson on the hard drive may be a solution.

Conclusions

Cross platform development is still in its infancy. It has only been in the last few years that one could even transfer a simple text file between a Macintosh and a PC. It is time consuming and often solutions are found only through extensive experimentation with the hardware and software that one is currently using. New tools, utilities and upgrades are constantly entering the market place to make the task simpler. As standards further develop for the different hardware components and the software used to develop, transport, and run interactive multimedia applications and the Macintosh and PC platforms become more compatible as well, the ability to design and develop interactive multimedia tutorials for educational use will increase.

References

Corrigan, J. (1994). Computer graphics secrets & solutions. San Francisco: Sybex.

Jerram, P.& Gosney, M. & Billups, S. & Poole, D. & Schussler, T. & Yavelow C. & the editors of Verbum Magazine (1994). Multimedia power tools. New York: Random House.

Perry, P. (1994). Multimedia developer's guide. Indianapolis: Sams Publishing.

Poor, A. (1993). The perfect display. PC Magazine, 147 - 181.

Small Groups, Computers and the Fundamental Theorem of Calculus

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The University of Connecticut is in the fifth year of an NSF-supported program to integrate the use of computers into our three-semester calculus sequence. The principal investigator on the project is Jim Hurley, who also wrote the text we use [H]. I have been involved for the past two years. The Department of Mathematics has a computer lab with 35 Macintosh II and SE/30 computers. Those machines are being replaced by Power Macintosh 7100's with the help of a "Yankee Ingenuity" grant from the state of Connecticut. Our students spend one of four weekly classroom hours in the lab. They work primarily with True BASIC programs written in-house for the calculus sequence.

The reason we use True BASIC is part of a larger paradigm about the role of computers in mathematics education. First, we believe that computers can help with the understanding of concepts. There has been widespread discussion of this issue. Most seem to agree that the graphical capabilities of a computer can add considerably to topics such as slope of a tangent line or area under a curve. We also feel that students can learn mathematics by examining simple computer code, like that used in True Basic. The idea of Riemann sums is handled easily by the computer, in a way that students can grasp readily, thereby increasing their understanding of a fundamental concept. A second use of computers is in numerical calculation. Hitherto inacessible problems are handled easily with the power of rapid computation. Thirdly, we believe that students benefit from the output generated by the computers. Group projects, discussed in more detail below, are often considerably enhanced by graphs, tables and other computer-generated information.

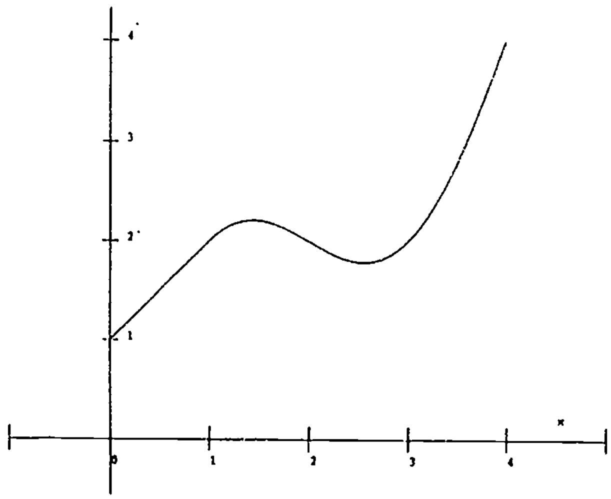
The allocation of time in the computer labs to the various aspects of computer use is eft up to the individual instructor. My inclination is to spend slightly less time discussing

[1] Work supported in part by NSF grant DUE-9252463.

Perry, P. (1994). Multimedia developer's guide. Indianapolis: Sams Publishing.

Poor, A. (1993). The perfect display. PC Magazine, 147 – 181.

code and slightly more time on cooperative projects like the one we use to illustrate the fundamental theorem of calculus. The students, in groups of two or three, first run a program that draws the following graph on the screen:



If they examine the code of the program, they can see that the function used is:

$$f(x) = \begin{cases} x+1, & \text{if } 0 \leq x \leq 1 \\ x + \sin(\pi x/2), & \text{if } 1 < x \leq 4 \end{cases}$$

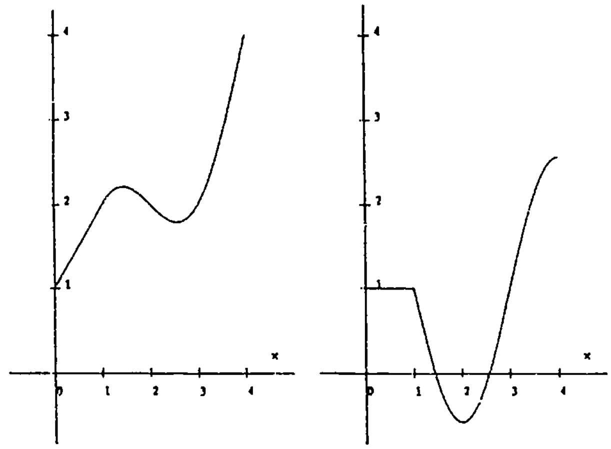
The first few lines of code, reproduced below, look remarkably similar to this standard way of writing the definition of f on a blackboard or in a text. They illustrate the ability of True BASIC to capture the essence of key mathematical ideas in a simple, easily grasped format.

```
def f(x)
    if 0 <= x and x <= 1 then let f = x + 1
    if 1 < x and x <= 4 then let f = x + sin(pi*x/2)
end def
```

The groups are asked to graph the derivative of the function by estimating the slope of the tangent line to the graph at a number of points. During this exercise the instructor walks around offering hints and suggestions, or asking questions. After about ten minutes, the students are told to run a program that graphs the function and its derivative side by

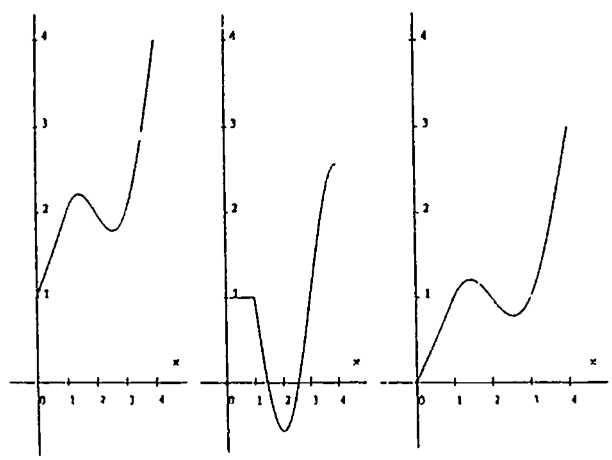
side:

Graph of f and f'



They are invited to make comments on their graphs to explain how errors might have arisen. Next we ask them to graph the area under the graph of the derivative from 0 to x, that is, to graph the function $F(x) = \int_0^x f'(t)dt$. They can do this by picking values for x and estimating the area represented by the integral. Again the instructor moves around "facilitating." Finally, the students run a program that graphs the function f, its derivative f' and the indefinite integral F side by side:

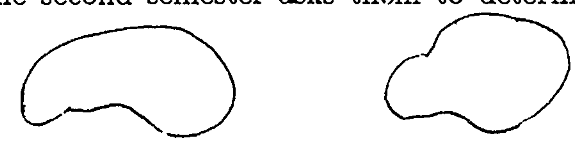
Graph of f, f' and F



As before, the students can examine the errors in their own graphs. We also ask them to explain (in writing) why the first and third graphs "look the same" and why the third graph is "shifted down". At the end of the lab, each group hands in two graphs

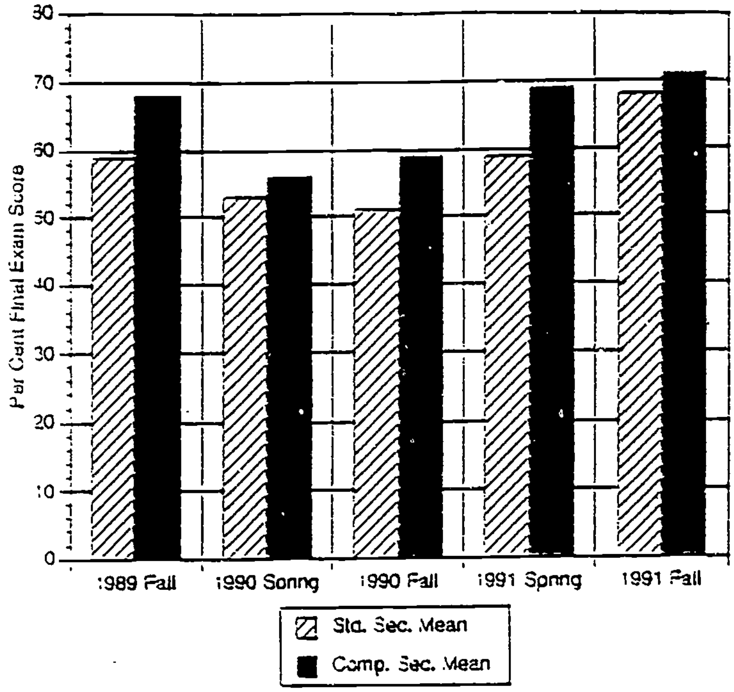
(with annotated errors) and a discussion that we hope involves mention of the fundamental theorem. The exercise seems to be successful in forcing students to grapple with at least the graphical aspects of the theorem. Indeed, in supervising this lab, I have been surprised by my own new insights into the mathematics. Moreover, in demonstrations of the project to colleagues, I have noticed that the students and I are not the only ones who are forced to change paradigms!

Not every calculus teacher is lucky enough to have easy access to a well-run computer lab. But everyone can experiment with the small-group concept. In my calculus sections, I divide the students into groups of four and devote one class period a week to group projects. To complete these, the group must usually meet outside of class as well. For example, the first project of the second semester asks them to determine which is the smaller of two "lakes":

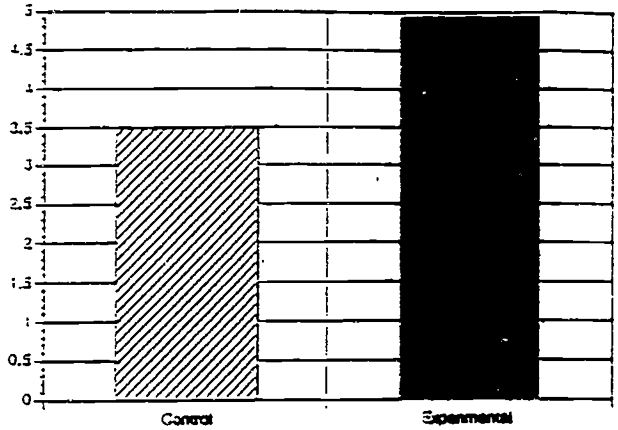


The Fish and Wildlife Service wants to use the smaller for a Purple Loosetrife eradication experiment. I try to guide the students toward constructing grids and counting rectangles. But often their creativity frees them from my Riemann sum chains. They cut out the shapes and weigh them; or hang them from a homemade balance; or cut up one into pieces that can be glued inside the other. It's a marvelous exercise for opening up the communication lines, for helping students connect.

Statistics gathered by our project suggest that students in the sections that use computer labs and small groups are learning more and coming away with a more positive attitude about mathematics. The first bar graph below compares the performance of students in "standard" sections with those in "computer" sections. The second graph compares persistence in pursuit of majors in mathematics, science and engineering. It shows the average number of key courses taken by students enrolled in calculus during the 1989-90 academic year.



Mean Scores on Common Final Exams



Mean Number of Key Post-Calculus Courses Taken after First-year Calculus

Beyond the statistics, I can tell you about classroom atmosphere. In the two hours a week that I still devote to "standard lectures" in calculus, an amazing transformation occurs. Students talk. To me, to each other. They ask questions and challenge things I say. It's quite a change from the stultifying silence that used to blanket my calculus classes (once I stopped droning). So try small groups, just once or twice if you're dubious. Read the article by Julian Weissglass [W]. Better yet, attend a small-group workshop. None of us has all the answers for teaching calculus. But all of us can improve. That involves trying new things – and small groups are a good place to start.

REFERENCES

[H] James F. Hurley, *Calculus: A Contemporary Approach*, McGraw-Hill Custom Publishing, New York, 1992.

[W] Julian Weissglass, *Small-Group Learning* Amer. Math. Monthly Vol 100 No. 7 (1993), 662-668.

"Current Technologies in Science Teaching"
Designing A Course on Technologies for Prospective Teachers

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Abstract: Most teacher preparation institutions are struggling with the question of how best to prepare students to use educational technology effectively. The University of Northern Iowa has chosen to do this by instituting a course "Current Technology in Science Teaching" which is required of all teaching majors in the sciences. The course is about evenly divided between learning specific techniques and considering pedagogical topics. Among the techniques introduced are those for the use of spreadsheets for data analysis and graphing, microcomputer-based laboratory probes, videodisc, CD-ROM, e-mail and computer conferencing. The pedagogical topics include software selection and evaluation, implementing technology in instruction, and legal and philosophical issues raised by new technologies. The paper discusses the issues of infusion of these topics in existing courses versus a separate course, stress on specific techniques or on general pedagogical methods, and the selection of the most useful topics and skills.

It seems unnecessary to give an extended rationale for the need to prepare teacher education students for using technology. Many studies and groups have bemoaned the inadequate job now being done and argued for improvement. Iowa, like most states, has a requirement for teacher licensure of some preparation in education media, and all teaching majors at the University of Northern Iowa are required to complete a two credit course in this area. In the science education program we felt a need for additional work, both because of the limited amount that can be accomplished in a single two credit course and because of the more extensive and sometimes unique uses of technology in science teaching.

Curriculum Issues

How is this best accomplished? While there may be general agreement on the need, there is less agreement on whether to accomplish this preparation by a separate course specifically on using technology in teaching or to add this topic to those already included in the science teaching method course (or courses, in our case). In our program there was a feeling that the ideal situation would be to incorporate this topic into the present science teaching methods courses, but it was recognized that this would be difficult to accomplish. At our institution we have a two part science methods program. One course, entitled Orientation to Science Teaching, is for all secondary level teaching majors in any of the sciences. Each student then takes a second course which provides a focus on the curriculum in his or her specific subject area. Orientation to Science

Teaching already included a great number of different topics. The faculty who taught it did not feel much enthusiasm for nor did they feel they had the background to include the additional topic of using technology. It was decided instead to institute a new course, Current Technologies in Science Teaching. This course has now been taught for six years by Dr. Roy Unruh and by the author.

Course Design

Courses, workshops, and training sessions to help teachers use technology in teaching have been common for many years. The contents of these have varied widely, both over time and with the interest of the presenters. Even within programs to prepare teachers to use computer-based instructions, there have been shifts from learning about computers, to learning programming languages, to stressing skills of operating particular software. What are the major unresolved issues? There seem to be two. The first issue is, should the focus be on teaching particular techniques and procedures (e.g. how to set up a spreadsheet) or on broader pedagogical methods and issues related to using technology (e.g. how to incorporate technology so it serves the instruction goals)? The second is: should one prepare teachers (or in our case, about-to-become-teachers) to operate in schools as they are now or in schools as we think and hope they will become with the advent of developing technologies? On the techniques versus pedagogical methods question, we tried for an equal balance (and seem to have accomplished this, as will be discussed later). On the present versus the future question, our hope is to deal with what we think will be available in the near future. However, it is difficult to keep ahead of the rapid rate of change and "the present situation" is very different in different schools. It is also certain that some of our ideas about what the future will be will turn out to be very far from correct.

The course which we developed and presented for six years is a one credit course, meeting once a week for two hours. It is offered in both spring and fall and is usually taken concurrently with our other two methods courses, Orientation to Science Teaching and one of several courses on the current curriculum. These two courses are each two credit hours, meeting for half of the semester. A prerequisite for the technology course is an education media course which treats the selection and use of educational technologies. It does give an introduction to the use of word processing, spreadsheets, and e-mail, but this introduction is necessarily rather brief.

Current Technologies In Science Teaching meets in a computer laboratory containing 14 IBM PS/2 Model 25's connected by a LAN to a IBM PS/2 Model 80 server running I-CLAS. All machines are equipped with IBM PSL laboratory interface systems. We also hold some meetings in a student computer lab which has 12 terminals connected to the UNI network giving access to local e-mail and to INTERNET. The two hours of class time per week for one credit hour is based on the idea that this is primarily a course of experiences and activities, without a lot of daily outside assignments.

Course Content

During the time that this course has been in existence, its contents have changed considerably. However, it has always included a large number of rather diverse topics, each touched on briefly. The current list of topics and the number of class hours dedicated to each is shown in Table 1. This is not the sequence in which the topics are considered. It should be noted that those topics earlier described as "particular techniques and procedures" and here listed under "New techniques and materials" take up 16 out of the 30 class hours, while most of the rest of the time (and the majority of the outside assignments) is devoted to "broader pedagogical methods". At least in these terms we have attained balance.

Table 1
Course Contents and Time Distribution

Topic	Hours of Class Time
Introduction to technology in teaching	
Need for preparation	
Special challenges of using technology	1
Getting information	2
New techniques and materials	
Spreadsheets	4
Microcomputer-based laboratory	3
Telecommunications	4
Videodisc and interactive video	3
CD-ROM	2
Selection and evaluation of materials	5
Using technology in a lesson	4
Issues in using technologies	2
Total Class Hours	30

The techniques for finding current information on recent developments in a field are very useful generally, but are of particular importance in a rapidly changing field such as educational technology. By requiring students to carry out searches of both the library on-line catalog and of ERIC on CD-ROM they are given practice in computer searches of data-bases, similar to techniques they may use later on distant data-bases through INTERNET. This also provides an introduction to the periodicals which are most useful to science teachers.

One of the techniques unique to science teaching is the use of microcomputer-based laboratory equipment. About one third of the students in the course have had some experience with such instruments, but not enough to recognize their full potential. Most have had an introductory physics lab in either high school or college (and often remember it without much pleasure). Therefore, an activity on studying the motion of their own body using a ultrasonic motion probe shows them how technology sometime makes it possible to learn concepts in totally new ways. We can then discuss the benefits of real time graphic displays of data and the new insights which can be gained from them. For this we use the IBM PSL system and some of the lesson materials developed to go with it.

In the required course they have taken earlier on educational media the students have used spreadsheets to set up a grade sheet. The main emphasis in our course is on using spreadsheets to calculate a function of a variable and to display a graph of the results. Then they investigate how the graph varies as the coefficients of the various terms are changed. The final step is to find the set of coefficients which will make the function match a set of given data. For all of this we use Quattro Pro since we have it on our LAN. The IBM PSL can export data in a form acceptable to Quattro Pro.

Our most recent development in the course has been in giving increasing attention to telecommunication. UNI is served by a DEC Alpha AXP machine which handles e-mail, a conference system,

and access to NEWS and to INTERNET. The use of e-mail and the conference system (with a conference set up just for the members of this course) are introduced in one of the first sessions of the course. Students are then expected to check into the conference at least once every other week. Topics are set up for them to ask questions or contribute suggestions about each of the course assignments. For some assignments their only required submission is a brief report left in the conference. This last semester several lively discussions also developed about what people were going to do or did over spring vacation, etc.. E-mail is used to send announcements about course changes and comments to particular students related to course work. Another requirement is to send e-mail to someone at another institution and to get a reply back. The other activity on telecommunication is to use TELNET to access either NASA's SPACELINK or Argonne's NEWTON. A class session at a lab with sufficient terminals gets them started. They then follow up outside of class to investigate these resources in more detail.

As a background for looking at video and CD-ROM materials we spend some time discussing various ways of electronically storing information, with analog or digital signal, and by magnetism or surface shape. The relative advantages and disadvantages of each are discussed and examples are brought out. This helps explain why there is such a multitude of systems, some of which can be combined while others cannot. Neither videodisc nor CD-ROM is very familiar to most, although they have all heard the terms. We have only one system available (a videodisc player connected to a Macintosh with a CD-ROM and a videodisc control program) with a limited collection of materials. A class presentation is sufficient to give an overview of what is available, how to use it, and what it can do. The students are expected to spend about an hour outside of class reviewing some materials, either on videodisc or CD-ROM, and then to submit a brief report on their experience and reactions.

The two topics that take almost a third of the class time and also relate to the major outside assignment are (a) selection and evaluation of materials, and (b) planning how to incorporate some technology into a science lesson. In the terminology of this course, "selection" is finding out from software guides and directories what materials on a given topic are available. "Evaluation" is trying out and judging the software. It is not feasible to get review copies of whatever the students find of interest from the literature, and thus the reviews are limited to software available on campus.

In the main methods course, Orientation to Science Teaching, which most students are taking concurrently with the technology course, they develop a complete lesson plan and then teach it to students at our laboratory school. In the technology course there is a review of this work on various approaches to lesson planning, but it is quite brief. In class all the students review the same program in small groups and then plan a possible lesson using it. Reports on these at the next class meeting allow discussion of the various functions that technology can play in a lesson. Our science education program stresses the learning cycle as a teaching model. For their individual lesson plans the style of lesson is left open, but they are required to prepare some type of supplemental or ancillary material to be used by the student with the technology. It can be an instruction sheet, a set of questions, a source of information needed to run a program, etc.. A detailed lesson plan is not required for all parts of the lesson, but they must give a description of the introduction of the technology, how it is to be used and what will be done to provide closure.

The final topic in Table 1, which is usually discussed near the end of the course, is on two types of issues concerning using technology. One type relates to legal issues about fair use and copying. These have become even more complex with the convergence of video and computer graphics. The other type relates to the appropriate use of technology in education in terms of cost versus benefit, real experiences versus simulations, and development of personal skills versus using technological tools.

Conclusions and Questions

As important as if is to learn *about* using technology, we feel it is equally important that our teaching majors learn *by* using technology and this should happen in the broadest possible context. Increasing the use of technology-based instruction in various science courses has been aided by the fact that the science education faculty at UNI are also members of the various science departments, and are themselves involved in teaching introductory courses in biology, chemistry, earth science, and physics. Those faculty who teach Current Technologies in Science Teaching have taken the lead in obtaining technology-based curriculum materials and equipment so that they may be included in the curriculum courses. We have recently encouraged the science education faculty members to increase their use of telecommunication, for communication with fellow faculty members and with our teaching majors. The goal is to insure that the students continue to use the skills they learn in Current Technologies in Science Teaching

The development of a separate course on this topic has meant that our students do get a significant introduction to using technology, taught by faculty who can focus on keeping abreast of this rapidly changing field. This seems preferable to a situation in which everyone agrees that using technology should be incorporated into all aspects of the methods component, but no one ever actually accomplishes a significant inclusion. We feel we have succeeded in providing our students with a variety of experiences in using technologies in teaching science. Whether these are sufficient to insure that they will be able and interested in applying technology when they begin teaching is the more important question and the more difficult one to answer. There is so much variability in the extent to which technology is used in different schools and classrooms that it does not seem possible to test the effect of this course on the practice of our graduates.

The fact that this paper describes what is being done at UNI does not imply we feel certai' ' ıt these are the best choices. The three issues describe above (separate course or infusion, techniques of (_ ration or pedagogical methods, and the choice of the most useful topics and skills) deserve more discussion by all those in science teacher preparation. It is hoped that this report of work in progress will contribute to such a discussion.

Dr. Roy Unruh made major contributions to the development of the course described here. Acknowledgement is also made to IBM for a gift of equipment and software under the IBM Program for Teacher Preparation and Enhancement In the Use of Available Technology

Eliminating the Pedagogy of Poverty in Mathematics and Science Classrooms Through Technology Use

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Abstract. This article discusses the potential of using technology as a catalyst to restructure mathematics and science classrooms. First, problems associated with the pedagogy of poverty model that is prevalent in most mathematics and science classrooms are discussed. Next, the current status of technology use in mathematics and science classrooms is examined. Finally, the article describes how technology can eliminate the pedagogy of poverty in mathematics and science classrooms by changing the current model of teaching and learning to one that emphasize more active student learning and changing the role of teachers from a deliverer of knowledge to one of a facilitor of learning.

Addressing the problems of inner-city schools is one of the most important national educational issues (Cuban, 1989). Nowhere are the social implications of increasing numbers of disadvantaged families in inner cities more prevalent than in the large, urban school districts where the deleterious conditions of underachievement, student and teacher alienation, and high drop-out rates exist. Furthermore, many of the physical structures and facilities in inner-city schools are abysmal and in desperate need of rehabilitation (Piccigallo, 1989). Those students attending inner-city or ghetto schools represent the most imperiled group of our increasing numbers of students at risk of failure (Boyd, 1991).

There are several critical problems that have been associated with the academic underachievement of students in urban schools. Some educators, for example, have argued that macro-level or distal variables like the high levels of crime, unemployment, dependency, broken families, illegitimacy and concentrated poverty have caused the deterioration of urban schools. On the other hand, other educators have focused on more proximal or "alterable" educational variables that can be changed and lead to improved outcomes for students who are at risk of failure. Two such "alterable" variables that have been found to be associated with the underachievement of students in urban schools are: (a) the school climate or school environment, and (b) classroom instruction.

Several educators have recently argued that school systems, school programs, organizational and structural features of school, and the school environment contribute to the conditions that influence students' academic failure (Boyd, 1991; Cuban, 1989; Kagan, 1990; Waxman, 1992). From this perspective, many features of schools and classrooms are viewed as detrimental or alienating and consequently drive students out of school rather than keep them in (Kagan, 1990; Waxman, 1992). The school environment is the broader context or climate of the school that either facilitates or constrains classroom instruction and student learning (Shields, 1991). School environments that (a) alienate students and teachers, (b) provide low standards and low quality of education, (c) have differential expectations for students, (d) have high non completion rates for students, (e) are unresponsive to students, (f) have high truancy and disciplinary problems, or (g) do not adequately prepare students for the future are considered to be "at risk" (Waxman, 1992). Students who attend these at-risk school environments merit our special attention because if we can alter their learning environment, we may be able to improve both their education and their overall chances for success in society.

The other critical concern related to the academic underachievement of students in urban schools has to do with the current instructional approaches that are prevalent in most urban classrooms. Several studies, for example, have found that some teachers provide differential treatment for some types of students. In particular, studies have found that teachers praise and encourage minority students less often than their white classmates and that teachers sometimes have lower expectations for minority students than their white classmates. In addition, several studies have found that schools serving disadvantaged or lower-achieving students often devote less time and emphasis to higher-order thinking skills than do students serving more advantaged students (Coley & Hoffman, 1990; Padrón & Waxman, 1993; Waxman & Huang, 1994). Lower-achieving students and minority students have often been denied the opportunity to learn higher-level thinking skills because it has been believed that they must demonstrate the ability to learn the basics or lower levels of knowledge before they can be taught higher-level skills. Furthermore, there is generally an emphasis on remediation for low achievers, which has resulted in teachers' lower expectations for these students and an overemphasis on repetition of content through drill-and-practice (Knapp & Shields, 1990; Lehr & Harris, 1988). The result of these practices may lead to

students adopting behaviors of "learned helplessness" and having a passive orientation to schooling (Coley & Hoffman, 1990).

Haberman (1991) argues that the typical style of teaching that is prevalent in most urban schools constitutes a "pedagogy of poverty." He maintains that this teacher-directed, instructional style leads to student compliance and passive resentment as well as teacher burn out. Furthermore, he criticizes this orientation because teachers are generally held accountable for "making" students learn, while students usually assume a passive role with low engagement in tasks or activities that are generally not authentic. Several recent studies have examined classroom instruction for students in urban schools and found that this "pedagogy of poverty" orientation exists in many classrooms where there are predominantly minority students (Padrón & Waxman, 1993; Waxman & Huang, 1994). Consequently, this instructional approach for students which is quite prevalent in urban schools as well as most other schools across the country, may be one of the most serious problems educators need to address.

To address this critical problem of teaching in urban schools, educators need to focus on new instructional approaches for improving the education of students at risk. Although there have been many programs and school-based interventions that have been found to be effective for some types of students at risk of failure, these programs and interventions will not necessarily have long term effects because they do not alter the typical instructional approach that has been prevalent in schools for decades. The next section specifically describes some of the current problems and new focuses of mathematics and science instruction.

Mathematics and Science Instruction

Several reports have documented that schools, in general, are doing a poor job of helping students become mathematically and scientifically literate (Mullis, Owen, & Phillips, 1990; Secada, 1991). Results of the Third National Assessment of Educational Progress, for example, revealed that school have not been successful in teaching students how to analyze mathematics problems or to apply mathematical principles to non routine problems. The results indicated that only 43% of 13-year-olds could regularly solve two-step mathematics problems. Classroom observational studies in mathematics and science have also documented the lack of higher-level teaching in these classrooms as well. Padron and Waxman (1993), for example, found that mathematics and science teachers in urban schools were very effective in organizing their class and keeping students on task, but they very seldom taught or emphasized higher-level processes. These concerns have directed educators to develop new approaches that will transform teaching and learning in classrooms.

Alternative curricular and instructional innovations in mathematics and science have been explored the past few decades, but for the most part, none of them have had a substantive impact on the basic instructional approaches that exist today in science and mathematics programs. There has, however, been a shift of focus in science and mathematics from the traditional lecture and drill approaches to an emphasis on teaching for understanding and teaching in investigative ways (McKinney, 1992). In mathematics, this has meant a focus on the use of manipulatives and problem solving, while in science, the focus has been on innovative curricula that include hands-on experimental approaches (Epanchin, Townsend, & Stoddard, 1994). These shifts of emphasis, however, will not have any long-term effects unless there are mechanisms to foster their development and use. Consequently, technology is viewed as the catalyst for these proposed changes in mathematics and science instruction. The next two sections explain how technology is presently used in mathematics and science classrooms, and then how it can be used to transform instruction and eliminate the pedagogy of poverty model.

Technology Use in Mathematics and Science Classrooms

Mathematics and science education are two content areas where technology integration is being widely advocated by professional organizations, school-based educators, and teacher educators. There is evidence, however, that technology is not being widely used in mathematics and science classes. Using national data collected on 18,000 tenth grade students from the first follow-up survey from the National Educational Longitudinal Survey of 1988, Owens and Waxman (1994) found that about 90% of the tenth-grade students reported that they "very rarely" used computers in science for (a) writing-up experiments or reports, (b) collecting/analyzing data, (c) calculations, and (d) models and simulations. Furthermore, less than 4% of the students indicated that they used computers in science either "almost every day" or "every day." In the area of mathematics, Owens and Waxman (1994) found that about 84% of the students reported that they "never" used computers in their mathematics classes and only 3% indicated that they used computers "often." Only 28% of the students, however, responded that they "never" used calculators in their mathematics classes. About 38% of the students said they used calculators "sometimes," and 34% indicated that they used calculators "often" in

mathematics. Other studies have similarly found that computers are not widely used in mathematics and science classrooms (Becker, 1991).

Furthermore, when computers are used in mathematics and science, there is evidence that there are differences in how computers are used in schools with predominantly minority students. In those schools, students typically work on tutorial and rote drill-and-practice programs, while schools with students from higher-income families generally use computers for problem solving and programming (Cole & Griffin, 1987; Hativa, 1988; Office of Technology Assessment, 1988; Sutton, 1991). There is further evidence that indicates that teachers have differential expectations for students and consequently believe that drill and practices activities are more effective for lower-achieving students than higher-achieving students (Sutton, 1991; Cosden, 1988; Chan, 1989). These concerns are still so serious that some critics argued that we have created a "technological underclass" in our public schools (Piller, 1992). In other words, the way urban schools have often used computers in mathematics and science classes has often discouraged students from using them and has also created greater inequities between high-achieving and low-achieving students.

Improving Mathematics and Science Instruction with Technology

Although technology is not being widely used or appropriately used in most science and mathematics classes, many educators still maintain that technology can be effectively used to eliminate the prevalent pedagogy of poverty that currently exists in mathematics and science classrooms. Several educators, for example, maintain that technology can be the catalyst for effective school restructuring (Bell & Elmquist, 1991; Sheingold, 1990). They argue that technology can enhance and supplement traditional classroom instruction as well as offer a new way to deliver instruction (NEA, 1991; Office of Technology Assessment, 1988; Olsen, 1990; Polin, 1991; Rockman, 1991). Some of the specific beneficial roles of technology that they discuss include: (a) fostering students' problem solving and higher-level thinking (Dede, 1989; Held, Newsom, & Peiffer, 1991; Lieberman & Linn, 1991; Office of Technology Assessment, 1988; Olsen, 1990), (b) enhancing student-directed learning and autonomous learners (Bell & Elmquist, 1991; Held, Newsom, & Peiffer, 1991; Hornbeck, 1991; Lieberman & Linn, 1991), (c) providing diversity in instructional methods (Polin, 1991) and (d) becoming an effective management tool for teachers and principals (Bell & Elmquist, 1991; Braun, 1990; Hornbeck, 1991; NEA, 1989; Office of Technology Assessment, 1988; Polin, 1991). More importantly, technology-enriched classrooms can change the current models of teaching and learning that emphasize more active student learning (Sheingold, 1990) and changing the role of teachers from a deliverer of knowledge to one of a facilitator of learning (Wiburg, 1991a).

There is some recent evidence that suggests that technology can significantly improve the mathematics and science education of students in urban schools. Olsen (1990), for example, found that integrated learning systems significantly improved the academic achievement of minority students from several minority school districts across the country. This integrated learning system included (a) computerized, criterion-referenced tests that allowed for individualized assessment, (b) courseware providing interactive practice and feedback and covering basic skills, higher-order thinking, and problem solving, and (c) an instructional management system that allowed teachers to monitor and track students' progress.

In his report for the International Society for Technology, Braun (1990) examined several projects across the country that found that technology-enriched schools had a beneficial effect on student learning. He found several examples of technology that improved at-risk students': (a) attendance, (b) achievement, and (c) behavior. He also found several schools and districts that decreased the dropout rate for students at risk. Although much of the evidence that Braun (1990) cites is based on expert judgements and anecdotal information, there appears to be strong consistency across these and other findings to support his conclusions. Descriptions of other technology projects such as Gross (1990), Kephart and Friedman (1991), and Wiburg (1991b) all involve students at risk and all support Braun's findings.

There is also recent research that has examined the specific ways technology impacts students at risk. Hornbeck (1991), for example, lists several generic characteristics of technology that helps students at risk: (a) motivational, (b) non-judgmental, (c) individualizes learning, (d) allows for more autonomy, (e) gives prompt feedback, and (f) allows for mastery of content at one's own pace. Since students at risk are often disengaged from schools, Cantrell (1993) points out that the use of computers diminishes the authoritian role of the teacher and also decreases situations where students could be embarrassed in class for not knowing answers. DeVillar and Faltis (1991) also discuss the effectiveness of technology for language minority students by describing how computer-integrated instruction facilitates social integration, communication, and cooperation. Finally, one of the most important outcomes of technology-enriched classrooms is that it can help reduce or eliminate the "pedagogy of poverty" that exists in most urban classrooms (DeVilla & Faltis, 1991).

Summary and Conclusions

One of our key educational goals is for all students to become independent thinkers and learners and have the confidence, skills, and knowledge to solve problems (Bransford, Sherwood, Vye, & Rieser, 1986). One of our key educational problems is that we often teach at-risk or disadvantaged students less than they are capable of learning (Knapp & Shields, 1990). There can never be equality of educational opportunity as long as some educators maintain attitudes that low achievers have less need for thinking skills than high achievers (Foster, 1989). We need to empower *all* students with the thinking skills that will help them help themselves. Computer-enriched instruction has the potential for deeping classroom instruction, making it more meanful, and assisting the learning of higher-order thinking skills (Niemic & Walberg, 1992). When technology is used this way as an instructional tool it can eliminate the pedagogy of poverty in mathematics and science classrooms and empower **all** students with the thinking skills that will help them help themselves.

References

Becker, H. J. (1991). Mathematics and science uses of computers in American schools 1989. *Journal of Computers in Mathematics and Science Teaching, 10*(4), 19-25.

Bell, T. H., & Elmquist, D. L. (1991). *How to shape up our nation's schools.* Salt Lake City, UT: Terrel Bell & Associates.

Boyd, W. L. (1991). What makes ghetto schools succeed or fail? *Teachers College Record, 92*, 331-362.

Bransford, J., Sherwood, R., Vye, N., & Rieser, J. (1986). Teaching thinking and problem solving. *American Psychologist, 41*, 1078-1089.

Braun, L. (1990). *Vision: TEST final report: Recommendations for American educational decision makers.* Eugene, OR: International Society of Technology in Education.

Cantrell, J. (1993). Technology's promise for at-risk students. *Thrust for Educational Leadership, 23*(2), 22-25.

Chan, C. (1989). Computer use in the elementary classroom: An assessment of CAI software. *Computers and Education, 13*(2), 109-115.

Cole, M., & Griffin, P. (Eds.) (1987). *Improving science and mathematics education for minorities and women: Contextual factors in education.* Madison, WI: Wisconsin Center for Educational Research.

Coley, J. D., & Hoffman, D. M. (1990). Overcoming learned helplessness in at risk readers. *Journal of Reading, 33 (7)*, 497-502.

Cosden, M. A. (1988). Microcomputer instruction and perceptions of effectiveness by special and regular elementary school teachers. *The Journal of Special Education, 22*, 242-253.

Cuban, L. (1989). At-risk students: What teachers and principals can do. *Educational Leadership, 46*(5), 29-32.

Dede, C. J. (1989). The evolution of information technology: Implications for curriculum. *Educational Leadership, 47*(1), 23-26.

DeVillar, R. A., & Faltis, C. J. (1991). *Computers and cultural diversity.* Albany, NY: State University of New York Press.

Epanchin, B. C., Townsend, B., & Stoddard, K. (1994). *Constructive classroom management: Strategies for creating positive learning environments.* Pacific Grove, CA: Brooks/Cole.

Foster, G.E. (1989). Cultivating the thinking skills of low achievers: A matter of equity. *Journal of Negro Education, 58*, 461-467.

Gross, B. (1990). Here dropouts drop in-and study! *Phi Delta Kappan, 72*, 625-627.

Hativa, N. (1988). Computer-based drill and practice in arithmetic: Widening the gap between high- and low-achieving students. *American Educational Research Journal, 25*, 366-397.

Haberman, M. (1991). Pedagogy of poverty versus good teaching. *Phi Delta Kappan, 73*, 290-294.

Held, C., Newsom, J., & Peiffer, M. (1991). The integrated technology classroom: An experiment in restructuring elementary school instruction. *The Computing Teacher, 18*(6), 21-23.

Hornbeck, D. W. (1991). Technology and students at risk for school failure. In A. D. Sheekey (Ed.). *Educational policy and telecommunications technologies* (pp. 1-7). Washington, DC: U. S. Department of Education

Kagan, D. M. (1990). How schools alienate students at risk: A model for examining proximal classroom variables. *Educational Psychology, 25*, 105-125.

Kephart, D. A., & Friedman, J. E. (1991). Integrating technology for at-risk students. *Computers in the Schools, 8*(1/2/3), 215-217.

Knapp, M. S., & Shields, P. M. (1990). Reconceiving academic instruction for the children of poverty. *Phi Delta Kappan, 71*, 753-758.

Lehr, J.B., & Harris, H.W. (1988). *At risk, low-achieving students in the classroom.* Washington, D.C.: National Education Association.

Lieberman, D. A., & Linn, M. C. (1991). Learning to learn revisited: Computers and the development of self-directed learning skills. *Journal of Research on Computing in Education, 23,* 373-395.

McKinney, K. (1992). *Improving math and science teaching.* Washington, DC: Office of Educational Research and Improvement, U.S. Department of Education.

Mullis, I. V. S., Owen, E. H., & Phillips, G. W. (1990). *Accelerating academic achievement: A summary of findings from 20 years of NAEP.* Princeton, NJ: National Assessment of Educational Progress.

National Education Association. (1989). *The report of the NEA Special Committee on Educational Technology.* Washington, DC: National Education Association.

Niemiec, R. P., & Walberg, H. J. (1992). The effects of computers on learning. *International Journal of Educational Research, 17,* 99-108.

Office of Technology Assessment (1988). *Power on: New tools for teaching and learning.* Washington, DC: U. S. Government Printing Office.

Olsen, J. B. (1990). Learning improvement results from integrated learning systems for underachieving minority students. In J. G. Bain & J. L. Herman (1990). *Making schools work for under-achieving minority students: Next steps for research policy, and practice* (pp. 241-255). Westport, CA: Greenwood Press.

Owens, E. W., & Waxman, H. C. (1994). Differences among urban, suburban, and rural high schools on technology use in science and mathematics. In J. Willis, B. Robin, & D. A. Willis (Eds.) (1994). *Technology and teacher education annual 1994* (pp. 589-592). Charlottesville, VA: Association for the Advancement of Computing in Education.

Padron, Y. N., & Waxman, H. C. (1993). Teaching and learning risks associated with limited cognitive mastery in science and mathematics for limited-English proficient students. In Office of Bilingual Education and Minority Language Affairs (Eds.), *Proceedings of the Third National Research Symposium on Limited English Proficient Students: Focus on middle and high school issues* (Vol. 2, pp. 511-547). Washington, DC: National Clearinghouse for Bilingual Education.

Piccigallo, P. R. (1989). Renovating urban schools is fundamental to improving them. *Phi Delta Kappan, 70,* 402-406.

Piller, C. (1992). Separate realities: The creation of the technological underclass in America's public schools, *Macworld, 9*(9), 218-231.

Polin, L. (1991). School restructuring and technology. *The Computing Teacher, 18*(6), 6-7.

Rockman, S. (1991) Telecommunications and restructuring: Supporting change or creating it. In A. D. Sheekey (Ed.) *Educational policy and telecommunications technologies* (pp. 24-35). Washington, DC: U. S. Department of Education.

Secada, W. G. (1991). Selected conceptual and methodological issues for studying the mathematics education of disadvantaged. In M. S. Knapp & P. M. Shield (Eds.), *Better schooling for children of poverty: Alternatives to conventional wisdom* (pp. 345-395). New York: Academic Press.

Sheingold, K. (1990). Restructuring for learning with technology: The potential for synergy. In K. Sheingold & M. S. Tucker (Eds.), *Restructuring for learning with technology* (pp. 9-27). New York: Center for Technology in Education, Bank Street College of Education.

Shields, P. M. (1991). School and community influences on effective academic instruction. In M.S. Knapp & P.M. Shields (Eds.), *Better schooling for the children of poverty: Alternatives to conventional wisdom* (pp. 313-328). Berkeley, CA: McCutchan.

Sutton, R. E. (1991). Equity and computers in the schools: A decade of research. *Review of Educational Research, 61,* 475-503.

Wiburg, K. M. (1991a). Teaching teachers about technology. *Computers in the Schools, 8*(1/2/3), 115-129.

Wiburg, K. M. (1991b). Three schools in which teachers have successfully integrated technology and teaching. In D. Carey, R. Carey, D. A. Willis, & J. Willis (Eds.), *Technology and teacher education annual 1991* (pp. 238-243). Greenville, NC: Society for Technology and Teacher Education.

Waxman, H. C. (1992). Reversing the cycle of educational failure for students in at-risk school environments. In H. C. Waxman, J. Walker de Felix, J. Anderson, & H. P. Baptiste (Eds.), *Students at risk in at-risk schools: Improving environments for learning* (pp. 1-9). Newbury Park, CA: Sage.

Waxman, H. C., & Huang, S. L. (1994, April). *Classroom instruction differences between effective and ineffective inner-city schools for language minority students.* Paper presented at the annual meeting of the American Educational Research Association, New Orleans.

Understanding Science: Visualizing the Molecular World and Simulating the Equipment

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Abstract: Multimedia modules are being used as a tool to improve science teaching in a laboratory setting. Screen features and overall layout were carefully designed taking into account pedagogical and cognitive implications of the learning process: on-screen information is presented to the students in a non-linear fashion; numerous branching points, layers and "food-for-thought questions" force the students to become actively involved in the learning process. Photos, movies, illustrations, and animations help students to visualize the experimental steps and the equipment set-up, as well as the events happening on the molecular level. Simulations allow students to practice the use of or the set-up of equipment. Built into the modules is a system that allows electronic communication between instructor and students, as well as on-line library research.

BACKGROUND

Much of modern biology requires a continuous application of chemistry and physics to biological problems. A deep understanding of biological systems and processes depends upon a meaningful inclusion of related knowledge from all the sciences. The interrelatedness of these sciences requires the student to form a matrix of knowledge that accommodates its expansion to include novel conceptual visions. In its absence, information remains a collection of trivia, data that have no unifying theme. From a didactic standpoint it is important to recognize that because the processes occurring at the molecular level are invisible to the naked eye, they are very abstract to students. Understanding the abstract is possible only when there is a capacity to visualize. Initially many students lack the ability to do so on their own; they cannot mentally construct the conceptual framework in which new knowledge can be fitted.

PROBLEM

Biology -- like all natural sciences -- is faced with an explosive growth of information that includes not only a parade of new data but, in addition, an ever-expanding catalog of continuously refined, improved, and novel techniques. This problem is aggravated by the rapidly increasing domination of research technology over the framework of conceptual advances in all fields of biology. Instruction needs to reflect the dramatic changes in the pace of scientific learning that especially characterizes the fields of molecular biology and biotechnology. Scientific results are superseded very quickly. Thus, it is mandatory that we familiarize students with the know-how of information acquisition and its effective use.

The difficulties in college science education described above generate numerous challenges for educators in both the lecture and laboratory setting:

- Scientific information, available electronically and on paper, is overwhelming. Today's scientists must have an ability to efficiently retrieve and sift this new information, to take advantage of the computer and network capacities in the scientific community, such as Internet, supercomputers, the protein data bank, and molecular modeling. Consequently, students must be trained in gaining access to, and use of, electronically available information.
- Concepts and knowledge have to be applied across scientific disciplines. Unfortunately, the nature of academia fosters a pigeon-hole mentality with its distinct departmental

boundaries, and neatly packaged courses, in which little time is used to illuminate the connections with previously learned material. Consequently, many students are deficient or totally incapable of thinking "interdisciplinary".

- Processes in modern molecular biology are invisible to the naked eye. Most students are unable to move comfortably from the macroscopic world to the abstraction of the molecular level.

The above stated problems are exemplified by the specific difficulties students face in laboratory courses in which typically a student does:

- not understand the concepts and principles underlying laboratory experiments; he/she is unable to hypothesize from a set of results, predicted or actual.
- not know why a procedure or experiment is useful to scientists at large, primarily because he/she does not understand its relevance to situations outside the teaching laboratory.
- not know how to develop an experimental protocol.
- not visualize events on a molecular level and therefore, never gains a grasp of the purpose of the experiment.
- not know or remember how to do basic calculations pertinent to the procedures.
- not have self-confidence; intimidation by sophisticated and often computer controlled experiments, and elaborate procedures described with lengthy, highly technical terms is rampant. He/She is alienated and discouraged to use the equipment without constant coaching by the TA, instructor, or technical staff.
- not have the ability to express him/herself clearly and concisely, particularly in writing.
- not have a specific, uniform learning style.

Personal instruction by a faculty member in a non-threatening setting, where the student may set the pace of instruction, ask many questions (both trivial and complex), practice the lab work and calculations, become familiar with the instrumentation, and take advantage of all resources available on the subject would constitute an ideal situation to overcome the above-stated problems to teach and learn techniques used throughout the experimental sciences. However, in the setting of a comprehensive university this model is impractical to consider. Large classes and TA-led instruction are a reality.

THE SOLUTION

A key thesis of our research is that interactive, computer-based multimedia packages provide a potent vehicle for addressing many of the problems listed above. Educational technology--hardware and authoring software--has advanced to the point that once expensive and complex tools can now be incorporated in the user-friendly environment of the classroom. Multimedia provides a method of linking information and concepts without requiring the reader to physically leave the learning environment he/she is in. A network of electronic screens represent a collection of related ideas and images, and allows the user to organize, store, and retrieve the information as needed. Information is presented in small packets (screens), but the sequencing of the packets is not forced on the student in a linear presentation dictated by the constraints of the printed page. The user can branch in as many directions as he/she likes, depending on needs and interests. Thus, learning is concept-driven, not text-driven, which should result in effective and lasting learning. Many methods of presentation can be used for the same concept. Multimedia can combine text, images, and animation all in a non-linear format. Such multi-sensory exposure, with the rate and nature of exposition controlled by the learner, is far superior to any single medium.

DESIGN CHARACTERISTICS OF THE COMPUTER MODULE

The philosophy that guided the development of our software was to create a computer program that helps both, instructor and students. Our goal was to make laboratory work more stimulating, interesting, and less intimidating, and at the same time allow the instructor to implement ideas, to increase the depth of presentation, and to use a variety of presentation formats. The software developed is considered to be an "interactive lab manual." Students have, at their fingertips, everything they need to prepare thoroughly for the laboratory session, homework assignment, or exam. The software is not only an animated manual that allows students to actually perform the experiment on-screen, but also a tutor, an on-line dictionary, and image

collection, and a communication tool between the instructor and student because of the email system that has been built into the computer module.

In the following table we outline instructional goals and our approach to reach those for the laboratory course Biochemical Techniques (BIBC 103):

Goal	Design Solution	Explanation
Ease of Computer Use	Intuitive Navigation	It is mandatory that students do not have to learn about the computer, but rather with the computer. Ease of use builds confidence and can help to overcome computer phobia.
Understand Course Outline	Course Web	BIbC 103 has three different facets: experiments, techniques, and calculations. Students fail to see the inter-relationship between these parts. The course web allows students to click on any experiment or technique to which technique they learn, or where a specific technique is being applied.
Modeling of Critical Thinking Skills and Professional Scientific Behavior	Scenario	A problem is presented and students help establish the questions a scientist needs to ask in order to find the answer. Students are lead through the development of a protocol outline, and shown how to use library resources and discuss ideas with colleagues.
Protocol Outline	Flowchart	The flowchart shows the sequence of experimental steps, thus creating an experimental framework
See Interrelated-ness of the Sciences	Extensive Branching	Extensive branching, i.e. concepts and ideas are explained in an "onion type" fashion: information is presented in numerous layers, from basic to more complex. Explanations of chemical and physical facts that the students are supposed to know already from previously taken classes can be accessed via branches off the main presentation line.
Accommodate Diverse Learning Styles	Extensive Branching;	The student decides how deep she wants to "dig," which areas have to be reviewed; graphics, animation, and simulations cater to visual learning style.
Active Learning	Branching; Food-for-thought-questions; Email to Instructor;	Food-for-thought questions challenge students reasoning skills; interaction with the instructor is possible via lab journal and email.
Visualization	Slide images, Video, QuickTime movies electron micrographs, Animation	Help is provided in two areas: to see the experimental steps, equipment set-up, etc. and also to visualize what is happening on a molecular level.
Simulation	Realistic interactive Animations	Students can practice the set-up of equipment, physical manipulations of materials, and operation of instruments.
Networking	Built in access to Internet and university electronic communication system.	Students will have access to the world of MELVYL, InfoPath, and all resources that come with being part of UCSD and Internet.

SPECIFIC EXAMPLES

1. Experiment: Separation of Photosystems I and II from Spinach.

In the design of this module we carefully addressed the problem areas identified above. Experimental design is taught, as well as the scientific relevance of the experiment. The underlying physical and chemical principles are continuously presented, and students decide whether to explore them further or not. The stimulus to do so is provided by numerous food-for-thought questions requiring on-line answers from the students. Students learn how to carry out experimental steps and at any time can find out what happens on the submicroscopic level.

In other words, the package, as it has been designed, allows the student a great deal of flexibility. For example, in the course of preparing a density gradient for rate-zonal centrifugation a student may branch from the main step of the experiment to learn how to set-up a gradient maker, or how to prepare the gradient, or how rate-zonal centrifugation works, or how a vertical rotor differs from other rotors, or, more generally, they may branch to an entire instructional module on the technique of centrifugation.

The package is flexible for the instructor also. A branch can be modified without changing anything else. Custom-tailored modules can be integrated with more generic modules such as electrophoresis or chromatography. As developments occur, or as equipment is changed, the module can be adapted quickly with new images and text that allow it to remain current. The experiment in which photosystems I and II are isolated from spinach leaves has received an enthusiastic response from the students. Students not only give the instructional method high praise, but they are understanding more and enjoying the work more. Our methods show great promise as stimulants to student learning. They offer a painless way for novices to be introduced to a new topic, and for experienced students to review material in context.

2. Equipment: The Spectrophotometry.

This module describes light and its interaction with matter, Beer's law and its limitations, details about the operation steps needed for most modern UV-Vis spectrophotometers (including a working computer simulation of an instrument), applications, and QuickTime movies of the exact models used in our laboratories.

3. Tutorial: Acquiring Library Research Skills.

The library module has several components. It includes an introduction addressing how to approach library research and interactive tutorials on the use of Biological Abstracts, Chemical Abstracts, and Beilstein's Handbook of Organic Chemistry. Each library module is connected to the others, or can stand alone for instructional purposes. Students can be provided with a diskette copy to use on their home computers. The programs are also accessible on the campus network via InfoPath, as well as from all suitable terminals located inside the libraries.

SUMMARY

The flexibility of a multimedia, computer-based instructional system allows for the provision of information in a way that resembles more closely the way scientists think and acquire new knowledge: typically, both intellectual processes occur in a non-linear fashion, where new pieces of information are fitted into an existing framework of knowledge. Our computer packages also allow the acquisition of knowledge in a concept-driven and not text-driven fashion. Thus, the user actively constructs his/her own framework of knowledge at a user-determined pace. He/She is the director of the learning process. Research indicates that this will lead to highly effective learning which is characterized by a vastly increased retention rate. The use of computer modules, as one option for the presentation of the course material, caters to students who learn best visually. Students that belong in this category get more information from visual images (pictures, animations, graphics, etc.) than from written or spoken material. If something is simply said and not yet shown to visual learners (for example in a lecture), there is a good chance they will not retain it (Kleinman, et al.). Many students exhibit this learning style, but they are exposed to an education system that favors a word-oriented learning style. Multimedia packages available as part of the curriculum will reduce or remove that problem. Multimedia can provide the ability to present a variety of learning paths and concept connections. No book alone can compete with that flexibility.

References

Kleinman, R., Griffin, H., Konigsberg-Kerner, N., (1987). Images in chemistry. *Journal of Chemical Education, 64*, 766-770.

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Science Teacher Training with a Computer-Based Video-Profiling System

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Abstract: This paper describes the development and use of a computer-based video "profiling" system for pre and in-service teachers of science. The system is designed to be a formative evaluation tool for science education methods courses and other professional training activities that focus on skill development in the area of teaching methodologies. Preliminary results suggest the use of the system fosters detailed discussion and reflection by teachers on instructional strategies. Results also suggest a shift from predominantly deductive to more inductive instructional strategies on the part of teachers.

The issue of what constitutes "good" teaching and how to evaluate it has concerned teachers, teacher educators and the general public for a long time. Historically, evaluation has been based upon "opinion" of a principal or other supervisor who has been assigned the task of classifying, quantifying and summarizing observations of classroom instruction. A number of classification schemes have been developed especially from the period of Flanders' work (Flanders, N.A., 1960). Classification schemes for analyzing teaching performance have been refined over time to become more "objective" or performance oriented. While these schemes have been refined the emphases of these schemes and their inherent limitations persist. A major and continuing limitation is the focus upon the use of an external summative evaluator. Formative evaluation by the teachers involved has been largely neglected. Further, evaluation instrumentation techniques have not been adapted to the emerging use of computer and video technologies. The integration of a computer system and a videotape is a natural extension which helps overcome the need for an external supervisor and yet provides needed analysis of instructional performance information to the teacher. This is supported by research which suggests that enhanced formative assessment together with ease of data collection are advantages of using a computer in such an application (Helgeson, S.L. and Kumar, D.D., 1993).

The Computer-Based Video-Profiling system enables a teacher to use a HyperCard based computer program to simultaneously view and analyze a videotape of the classroom science lesson or microteaching episode according to categories of instructional events. To accomplish this, a previously taped lesson is played from a VCR into graphics card which then provides a real time digitized signal to a computer monitor for processing and display. A

References

Kleinman, R., Griffin, H., Konigsberg-Kerner, N., (1987). Images in chemistry. *Journal of Chemical Education, 64*, 766-770.

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specially designed Hypercard stack concurrently displays the necessary control buttons that permit a science teacher to automatically record both the frequency of different teaching events and the amount of time spent on those events. When the tape is finished the program also finishes and automatically displays a profile of the entire lesson for the teacher. The displayed profile can also be printed and used for reflective analysis by the teacher or pre-service teacher.

Since this project is aimed at assisting teachers in adopting a more inquiry oriented approach to science instruction the video profiling system incorporates an electronic modification of the Teaching Strategies Observation Differential (TSOD). The TSOD was originally designed for use by methods students for microteaching analysis (Yeany, R.H. 1978). When originally done it was in a paper and pencil format but here has been adapted and enhanced for a computer environment.

Using the enhanced TSOD in the video profiling system allows the time and frequency counts of inductive, deductive, student-centered and teacher-centered events to be recorded and printed out for any lesson. In addition, individual instructional events can be named and briefly described. Actual proportions of categories of events can be compared to ideal proportions for a given lesson. Novice teachers and experienced "traditional" science teachers often use excessive deductive and teacher-centered instructional events when inquiry teaching or inductive student centered teaching would be more desirable and effective.

Data, based upon preliminary observations of teachers working with the computer-based video profiling system, suggests there were changes from deductive to inductive teaching. In addition teachers showed an increased interest in lesson assessment and improved skills in both analyzing and classifying their teaching behaviors. Researchers hypothesize that using the computer-based video profiling system can significantly improve the skills of teachers in analyzing, planning and implementing inquiry oriented science lessons.

References

Flanders, N.A. (1960). Teacher influence, pupil attitudes, and achievement. Minneapolis: University of Minnesota (U.S. Office of Education Cooperative Research Project No. 397).

Helgeson, S.L., and Kumar, D.R. (1993). A review of educational technology in science assessment. *Journal of Computers in Mathematics and Science Teaching*, 12(3/4), 227-241.

Yeany, R. H. (1978). Effects of microteaching with videotaping and strategy analysis on the teaching strategies of preservice science teachers. *Science Education*, 62(2), 203-207.

Technology-Enhanced Physics Instruction

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Abstract: The Technology-Enhanced Physics Instruction (TEPI) Project has developed a working classroom model wherein both the techniques of technology-enhanced instruction are being researched and their efficacy in promoting student understanding and positive attitudes are being evaluated. The focus of the Project is on the implementation of computer-based simulations. However, several other forms of computer-based technology including microcomputer-based labs (MBL), interactive testing and multimedia applications are also being implemented. The technology has been introduced into Physics 11 and 12 and has been used throughout the whole year. Transmissive instruction has largely been replaced by teacher mentoring and small group activities at various classroom centers. Student response to their use of technology has been very positive.

a) Introduction

Most educationally interesting uses of technology require adjustments in the traditional roles and instructional procedures of teachers - adjustments that many teachers understandably resist through lack of training and effective models. It takes careful preparation and planning to realize the benefits of technology and to make innovative things happen. The novelty and the necessarily time-intensive preparation of technology-based instruction are significant barriers for many teachers - particularly those who have well-developed course plans and instructional strategies. Even for technology-oriented teachers, it is a major challenge to restructure courses and adapt teaching styles to take advantage of possibilities inherent in a technology-enhanced classroom. Major adjustments are also needed in student learning strategies and classroom procedures. The Technology-Enhanced Physics Instruction (TEPI) Project has been designed to research and disseminate the instructional strategies and classroom procedures that promote the best use of emerging technology in an environment in which the participating students perceive their use of technology, and that of their teachers, as an integral part of normal classroom procedures. The goal of the Project is to play a key role in promoting the use of technology-based instructional strategies, encouraging greater student enrollment in science and technology, and ensuring that science and technology are directed creatively in ways which enhance the quality of life.

The premise of the TEPI Project is that if technology-enhanced education is to become an essential part of the paradigms of science classrooms, technology applications must not be supplemental to the educational process but must be fully integrated into courses and programs. All teaching situations must be real and ongoing. Within the context of this Project, technology-enhanced instruction includes the use of computer-based simulations to develop and extend student understanding of physical relationships, the interactive use of computer-interfaced laserdiscs both by the teachers and by the students, the use of computer-interfaced probes and sensors in laboratory situations to collect data, the use of projection panels to present information and examples, the use of interactive testing procedures to assess student learning, and extensive use of computer applications to process and analyze data, and prepare and analyze tests. Implementing each of these technologies requires a significant departure from the traditional, transmissive procedures which characterize so much of introductory Physics instruction. Each also presents challenges to the teacher to implement on an ongoing basis.

Classroom Environment

The first stage of the TEPI Project was to established a suitable environment in which technology would be an integral, ongoing part of the instructional process. Through Project funding, the Physics classrooms at H. D.

Stafford and D. W. Poppy Secondary Schools in Langley, British Columbia, were equipped with a "state-of-the-art" teaching station, extensive multimedia equipment and eight student workstations. As the technology was gradually introduced in the spring of 1993, the Project team experimented with its use in preparation for its full implementation in the 1993-1994 school year in both Physics 11 and Physics 12.

During the summer of 1993, plans for a Multimedia Center were developed. This mobile Center contains the teacher's Macintosh Centris 650 computer, the active matrix LCD projection panel and high intensity overhead projector, a VCR, a laserdisc player, a CD-ROM player, a power amplifier and speakers, and a 12" TV monitor. The Multimedia Centers serve both as instruction stations for teachers and a multimedia workstation for their students. An additional function of these two mobile Multimedia Centers is to give all members of the two Science Departments access to the multimedia equipment as an encouragement to begin to incorporate technology-enhanced instruction themselves. Both units were custom built for the Project by the Langley School Board.

The eight Macintosh LC III student workstations were installed in the Physics classroom of both schools in early September, 1993, ready for the beginning of the school year. At Poppy, the installation of the student workstations proceeded smoothly. At this school, the student computers were positioned along the existing side and back counters. Cupboard doors were removed to give the students 'knee' room and roller-mounted keyboard trays were attached under the counter tops. The student workstations are networked to the teacher's computer and to the classroom LaserWriter 360 printer. The installation of the workstations was accompanied by a number of important room modifications, foremost of which was a rewiring of the room to give the teacher greater control of, and access to, classroom lighting. This teacher can now control the lighting in the classroom while seated at the Multimedia Center.

At Stafford, the installation of the student workstations proceeded less smoothly. This school was being extensively expanded and renovated during 1993 and 1994. The Physics classroom was slated for renovations in the spring of 1994, but, unexpectedly, these renovations commenced in the summer of 1993 with the result that the teacher was forced to start the year in an alternate classroom. The student workstations were installed in the Physics classroom in October, 1993 and have been used in the middle of a "work-in-progress" throughout the year. It is a considerable tribute to the construction of the Macintosh computers that they have continued to function flawlessly in this dusty environment. Unfortunately, computer discs did not fare nearly so well. The renovation of the classroom, however, did permit the rewiring of the lights, the installation of a dedicated phone line and white boards, and the installation of security measures in this ground-level classroom. Moreover, the teacher noted that had he not had the student workstations available, permanently installed or not, and his own computer and LCD projection panel, he would have been unable to maintain the quality of his Physics program this year in the midst of the school-wide chaos resulting from the ongoing renovations. At Stafford school, it was planned to provide one Stylewriter II printer for every two student workstations. These printers are extremely quiet and produce excellent output. Unfortunately, this procedure has not worked well. The Stylewriter II's experience intermittent problems when they are networked to two computers. The source of these problems has not yet been isolated. Funds are currently being sought to replace the Stylewriters with a LaserWriter 360.

Technology Implementation

The central focus of the TEPI Project is the use of computer-based simulations as both instructional and learning tools. By making Physics more visual (concrete) and animated, simulations promise to motivate students, broaden student understanding of scientific principles and encourage more students to enter and remain in scientific studies. Moreover, computer-based simulations permit the visualization of physical concepts and the manipulation of variables in a manner not possible otherwise. An essential characteristic of an effective simulation is its fit to the curriculum. 'Off-the-shelf' simulations frequently don't quite match the existing curriculum or the teacher's objectives and instructional style. Normally, such simulations must be used in lieu of suitable alternatives. For Physics instruction, however, there is a notable alternative - *Interactive Physics II™* - which is a simulation 'engine' or development tool rather than a fully-developed simulation. However, *Interactive Physics II™* has a 'steep' learning curve for the teacher-developer and requires technically proficient users to develop sophisticated simulations. Once developed, however, the simulations are 'user friendly'. *Interactive Physics II™* has been used extensively in the Project to create simulations specifically designed to meet the objectives of the Physics 11 and Physic 12 curriculum units. Many of these simulation were based upon the *Interactive Physics II Player™* Problems and Examples developed by Prentice Hall for both the Giancoli text, *Physics*, and the Fishbane, Gasiorowicz, Thornton text, *Physics for Scientists and Engineers*. (Giancoli's book, *Physics*, is the prescribed Physics 12 textbook in British Columbia.) In addition, the simulation, *Waves*, was incorporated into the Physics 11 unit, *Wave Properties*. While more

restricted in application than *Interactive Physics II™*, *Waves* shares with *Interactive Physics II™* a flexible design and good supportive materials. The Project hopes to incorporate more of the simulations from the *Waves* series in the 1994-1995 year.

While the focus of the Project remains on the implementation of computer-based simulations, other technologies have been implemented as well. In September, for example, the students were all introduced to *ClarisWorks* and *CricketGraph* and are encouraged to use these resources to prepare assignments and lab reports. The Scoring Edition of *LXR•TEST* is used to prepare and administer mastery-based pretests and tests. This edition of *LXR•TEST* contains advanced word processing, page layout and database management capabilities for the specific purpose of developing and maintaining large banks of questions and generating exams. Both teachers involved in the Project are members of a Province-wide consortium developing a large databank of Physics 11 and Physics 12 test items keyed to the objectives of the Provincial curriculum. The Scoring Edition of LXR•TEST can also be connected to an optical mark reader to score and analyze student responses thereby facilitating criterion-referenced testing, objectives-based assessment and analysis of instructional effectiveness. The Interactive Testing eXtension to *LXR•TEST* is used in the Project to able the students to complete the objective portions of their tests at the computer and get instant feedback. This extension is also used to assess the higher order thinking skills of the students via interactive questions which incorporate QuickTime movies of *Interactive Physics II™* simulations. Statistical data obtainable from *LXR•TEST* permits both teachers to analyze the exam results of each student objective-by-objective. Another technology that is being used is MBL. The sonic ranger, for example, has been very useful in introducing Physics 11 students to the concepts of motion and graphical analysis. The use of laserdiscs by both the teachers and the students has also been incorporated into the curriculum. The laserdiscs used this fall were the set prepared by the American Association of Physics Teachers - *Physics: Cinema Classics* - and the set, *For All Mankind*, from Voyager, Inc. Others are being considered for implementation in next year.

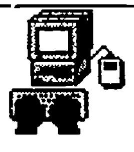
Classroom Organization

During the 1993-1994 school term, work on the Project was devoted to collaboratively establishing a working classroom model of technology-enhanced instruction in the two Physics classrooms - a process which required major restructuring of the instructional strategies of both teachers. A driving force behind the Project is a conviction that the most appropriate application of technology in science education is not merely to augment data delivery in conventional instruction, but to foster a model of teaching and learning based upon learners' mastery of information management and relationships. This model of technology-enhanced instruction has been developed to include the following strategies:

- active construction of knowledge by students rather than passive ingestion of facts;
- the use of sophisticated information-gathering tools that allow students to focus on testing hypotheses rather than on gathering and recording data;
- the use of multiple representations for knowledge, so that content can be managed by individual learning styles;
- collaborative interaction with peers similar to team-based approaches in modern work settings;
- individualized instruction that targets intervention keyed to each learner's current needs; and
- evaluation systems that measure the achievement of complex, higher-order skills rather than recall of facts.

A key to the establishment of this model was the design and preparation of student Study Guides for each unit. The Study Guides had to be explicit enough to give direction to the students yet flexible enough to encompass a range of learning styles and student abilities. The Guides outline the units' objectives, content and completion requirements. They include sample problems, assignments, student and teacher simulations, laserdisc based activities, labs, demonstrations, discussions, and self checks for understanding. The format of these Guides gradually stabilized as their use was evaluated. One feature that proved to be very effective was the use of 'standard' icons to flag specific activities. Some examples are shown in Figure 1.

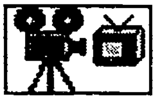
Students use these Guides to work through the units at their own pace, either individually or in small groups. Transmissive teaching is kept to a minimum permitting the teacher to work with individuals or small groups. Typically, in any given class, three or four different activities can be underway depending upon the students' rate of progress through the Guide. Whole class activities are generally restricted to teacher demonstrations, tests and some laboratory activities This structure puts the students in a position of assuming some of the responsibility for their learning but requires a careful 'bookkeeping' system to track student progress.



Self Check for Understanding...
Test your progress on the computer. Take the test "Wave Properties Self Check #1".
Your test will be marked automatically; print out the results on your test and hand them into the teacher.

Class Discussion: Notes & Problems
Your teacher will discuss the notes up to this point and clarify any points.

Computer Simulation Free Fall Experiment. Run the simulation **Free-Fall Exp't #1**
This simulation will lead you in the use of several of the above motion equations and serve as a model for solving problems involving acceleration due to gravity.



Multimedia Center:
View the laser disc sequence titled "Reflection of Water Waves" from the AAPT disc #2 side C.
Edit your sketch above if required.

Figure 1. Examples of the icons used to flag specific student activities

Results

1. The collaborative nature of the Project design has been extremely effective. The two teacher/researchers continuously give support and reinforcement to each other in developing and testing strategies and activities and the triad team approach has resulted in each member assuming 'ownership' of the Project and lessened the 'imposed from above' nature of the Project Director's suggestions and contributions. A similar effect is observable in the classrooms with the students taking greater ownership of their learning responsibilities and seeking help rather than commands from their teachers.
2. Both teachers have undergone a shift in their previous instructional strategies. Transmissive instruction is now kept to a minimum in both classrooms and individualized and group instruction is the norm. Frequently, one has to search to locate the teacher in the classroom. One indicator of the success of the Project's instructional model is that the teachers have consistently maintained their new instructional strategies throughout the year even when severely pressured by the demands of preparing new instructional materials and 'orchestrating' the multiplicity of classroom activities that the model engenders.
3. The computers were well received by the students. Most students seemed to adapt to the new structure and technology very well to the point that the computers are in almost constant use not only during class but before and after school as well - often as late as the teacher is willing to stay. In fact, some students request to use the computers during the teachers' preparation periods and even when the teachers are teaching junior division students. Another outcome of the use of the technology is the pride that the students seem to take in the work that they produce. Hopefully, the extra time that they now take in producing reports and assignments will translate into better understanding of concepts.
4. The computers engender student collaboration. Most of the students work in pairs or triads at the computer and at their desks. For example, one group of three Physics 12 students were observed to spend 10 minutes vigorously debating whether or not mass would affect the motion of an object sliding down an inclined plane in the simulation they were studying. These students were 'thinking' and 'talking' Physics! Such discussions are rare in traditional lab exercises.
5. The instructional model appears to be having a positive effect on students' 'on-task' behavior. Students enter the classroom ready to work and maintain that attitude throughout the class. The question, "Can we get started now on the computers, Sir?" is not uncommonly heard as the students arrive at class. Frequently, the teachers must interrupt the students to outline the day's expectations and give out announcements of upcoming activities at the beginning of the period.

6. The models effectively addresses different learning styles. For example, one particularly interesting result of the Project has been the reaction of a particular Physics 11 student. Clearly distinguishable from the majority of the students on the basis of dress and behavior, this student has thrived in the technology-enhanced Physics course, achieving the fourth highest mark in the class, while experiencing difficulty in other courses.

Future Plans

The Project will continue to develop its instructional model and curricular materials during the next school year. An assessment of student learning will be conducted over the summer when the results of the Province-wide Government Exams become available. In addition, data related to pre- and post treatment student attitudes toward science and technology will be analyzed over the summer. Student learning, particularly that related to higher order thinking skills, has been targeted for a specific sub-study, next year. In addition, the Project team will begin to present inservice workshops to science teachers throughout the Province. In conjunction with this dissemination phase, plans are currently under discussion with British Columbia's Open Learning Agency to produce three broadcast videos related to the Project.

References

Fishbane, Gasiorowicz, & Thornton, R., (1990). *Physics for Scientists and engineers*, Englewood Cliffs, NJ: Prentice Hall, Inc.

Giancoli, P. (1990) *Physics*. Englewood Cliffs, NJ: Prentice Hall. Inc.

LXR•TEST, Logic eXtension Resources, 7168 Archibald Avenue, Suite 240, Rancho Cucamonga, CA 91701-5061

Interactive Physics II, Knowledge Revolution, 15 Brush Place, San Francisco, CA 94103

Waves, LOGAL Educational Software and BBN Laboratories, WINGS for learning, 1600 Green Hills Road, P. O. Box 660002, Scotts Valley, CA 95067-0002

ClarisWorks, Claris Corporation, 5201 Patrick Henry Dr., Santa Clara, CA 95052

CricketGraph, Computer Associates International, INC., One Computer Associates Plaza, Islandia, NY 11788-2000

Physics: Cinema Classics, Ztek Co., P. O. Box 1055, Louisville, KY 40201-1055

For All Mankind, Voyager, 1351 Pacific Coast Hwy., Santa Monica, CA 90401

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Implications of Current Emerging Software Technologies on CAI (Computer Aided Instruction)

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Abstract: This paper addresses the implications of current emerging software technologies on CAI (computer-aided-instruction). Problems impairing the growth of CAI are highlighted. Recently emerging software technologies including: i) information handling; ii) GUI (graphical user interface); iii) programming methodologies; iv) expert system tools; and v) software platform are discussed. The implications and opportunities on CAI are elicited with a precalculus courseware built in light of the emerging software technologies also mentioned.

Introduction

It was not until the start of the PLATO computer-based educational system that sparked people's interests in CAI (Computer Aided Instruction) in 60s. However, the development of CAI has been slow because of the difficulties to produce "workable" and quality CAI. Among the problems, albeit the socio-managerial issues, are:

- *The visual problem.* The lack of visual aids or support in the exhibition of the semantics demanded of CAI. The mere provision of limited text-based graphics is inadequate.
- *The audio problem.* The lack of audio facilities support for the operations of CAI. This is especiall so for language learning CAI [Wong, 1989].
- *The feedback/response problem.* The problem related to the handling of the learner's feedback or response such that it could be monitored, diagnosed and used for adaptive instruction [Self, 1974; McCalla, 1990].
- *The expertise problem.* In essence, this refers to:
  i) The expertise dilemma. The program developer for CAI software ususally does not possess instructional expertise required of the courseware. He is also not expected of possessing the required expertise of the subject domain. Yet, this poses impediments to the development of the "really" desired courseware. On the other hand, if the author is to develop CAI himself, he may not have the programming expertise in developing CAI. Or, the developed CAI may only be using the underlying engine's capability partially. Experiences tell that to properly develop a quality courseware, in addition to computing knowhow, at least three areas of expertise are required: the knowledge of the subject domain, a competence in instructional or didactic strategy and communication capability. With one more, an understanding of the behaviour and reaction of the target leaners [VanLehn, 1988]. Needless to say, no single person has all these expertises.
  ii) The "intelligence" expertise problem. Whilst most courseware author should explore the possibility of exploiting AI (artificial intelligence), there is a general lack of expertise in developing more intelligent courseware. Not to mention the consensus problem on the theory of ITS (intelligent tutoring system) [Wu, 1993a].

On the other hand, the unprecedented zenith of technological advance has thrown the whole computing era from mainframes, to mini and then micros with myriads of useful products, from highly vertical to general purpose, produced. This trend of constant innovation renders yesterday's technological problems a memory

and drives future computing to a level of sophistication too complicated to be apprehended easily. What are the implications posed by this advent of advanced technologies, in particular software, on CAI?

In the following sections, we'll first give an account of the current scenario of emerging software technologies together with their possible impacts on CAI. The opportunities for developing more "advanced" CAI are then highlighted via an illustration, namely, a precalculus courseware.

Recent Emerging Software Technologies and Their Implications

As the recent advent of software technologies is too varied and diversified to be detailed fully here, only those that bear direct contribution to the essential characterizing dimensions of CAI [Wu, 1993b] are noted. For clarity, they are stated below:

- T (the number and composition of the teaching agents simulated by CAI)
- L (the number and composition of the learning agents, simulated or accomodated by the CAI)
- F (the form of interaction taken by the CAI)
- B (the bandwidth, that is the number of I/O communication channels used by the CAI)
- E (the degree of subject content elaboration allowable by the CAI, eg a hypertext-based system [Conklin, 1987] will allow a sophisticated elaboration of content while a simple programmed branching one won't)
- I (the use of the learner's information in guiding the adaptability of the tutoring system; basically it's related to the tutoring strategy and student modelling issues)

Information handling technology

The development of information handling technology has a direct bearing on the E (the degree of subject content elaboration) dimension of CAI. This dimension is a direct reflection of the CAI's structuring and organization of subject materials. In the hardware side we have the rising of massive storage technology such as optical disks for storing large amount of information. In the software aspect, perhaps the most significant recent development is hypertext [Conklin, 1987] where a dynamic, multi-way and multi-hierarchical access of information is made possible. Coupled with the recent advent of multimedia technology, hypermedia (hypertext + multimedia) systems are formed.

The impacts posed by hypertext are:

- The development of multi-threaded exploratory type CAI. A step beyond traditional CAI that's used to have programmed frames with each encapsulates a certain amount of subject knowledge [Price, 1991]. In other words, the retrieval of information content is hard-coded by the frame sequence of the CAI. With hypertext, CAI is liberated from such rigid access of information.
- The development of "deliberated" multimedia presentation. This point basically stems from the previous one. With multimedia-information abstracted as objects in the hypertext nodes [Edwards, 1992], a deliberated presentation in multimedia is made possible.

GUI (graphical user interface) software

The development of GUI (graphical user interface) software is characterized by the development of WIMP (window-icon-menu-pointer) concepts and the notion of WYSIWYG (what-you-see-is-what-you-get). Coupled with multimedia and multiple display windows with zoom-in and zoom-out capabilities, the interaction dimenison of CAI is magnified. That is, in our terminology, the dimensions F (form of interactioon) and B (bandwidth) are enhanced.

The impacts on CAI interaction are:

- Extension in semantics conveyance. Previously, the semantics of CAI information are mostly conveyed via text-based display and are therefore very limited. The emergence of GUI technology, with WIMP and WYSIWYG has extended such conveyance process from purely based on text to other

types of manifestation such as drawings, icons, and even animated graphics. Another extension is in the spatial display of information, especially in conveying an object's actual size and shape.

- More towards direct manipulation [Schneiderman, 1983]. Interaction with the user is one of the most significant operations of CAI. Direct manipulation - the ideal goal of seamless interaction between man and machine, will no doubt, be further taken one step towards the direction.

Programming methodologies

Recently, various uprising programming methodologies have drawn much attention from the computing arena. We'll mention three of them:

- OOP (object oriented programming) [Harel, 1992]. This is a programming approach whereby entities, together with its processing procedures (called methods), are identified and coded as objects in the software product. As such, the future reuse of objects (ie. the software) will then be facilitated.
- Visual programming [Chang, 1990]. This is the programming approach emphasizing the use of visual expressions (such as icons, drawings, and gestures) in the process of programming.
- "Programming by rehearsal" [Finzer, 1984]. This programming approach can basically be classified as a variant of visual programming whereby the theatre is employed as the operational metaphor. Programs are productions, in the theatrical sense made by performers (modifiable segments of program code). Programming is then carried out by rehearsal (ie. demonstrationally) of performers put on the stage.

Undoubtedly, the implementation for various dimensions such as F (interaction form), B (bandwidth manipulation), E (elaborativeness of content) and I (handling of learner's information) will be facilitated. While the impact from these programming approach remains to be seen, their presence have enabled various attempts in outlining a new architecture for CAI. Some examples are the bite-sized architecture mentioned by [Bonar, 1985], and the exploitation of object architecture in ITS [Richards, 1988].

Expert System Tools

Recent advent of software technologies has also brought in a large number of expert system tools enabling quick development of knowledge-based systems. Usually, these tools are in the form of shells [Mettrey, 1991] with a number of KR (knowledge representation) schemes available to users. In addition, users may select the inference approach for the derivation of solutions from the knowledge base.

The major impacts from such availability of expert system tools are:

- Quick prototyping of intelligent courseware. Since ITS, in a loose sense, is also a kind of expert system. The availability of shells, if properly chosen, would be of significant help in developing intelligent courseware.
- Allows for the embedding of intelligence to CAI. While a full intelligent courseware may not be possible, such shells however help in building some "intelligent" routines to be embedded in traditional CAI [Wu, 1992].

In other words, the implementation of the dimension I (handling of learner's information) for "adaptiveness" is enhanced.

Software platforms

Perhaps the most phenomenal event in recent emerging software is the rise of those "open" software platforms such as X-Window and Microsoft's Windows [Microsoft, 1985]. By "open", we means the platform supports and allows for the multi-linking of data and objects of software working it.

The impact on CAI from such open software platform can be tremendous, for example:

- In the authoring process. Previously, CAI development has been hampered by the lack of proper or powerful authoring tools. Most of these authoring tools are so general that they become limited when applying for a specific domain [Barker, 1987]. However, with the availability of open software

platform, users may choose various specialized software for the different tasks for CAI development without worrying "too much" for their integration. Moreover, concurrent development of courseware by independent workers is also made possible under the environment.

- In the operation of CAI. More versatile operation in both the development and production is made possible as such open software platforms encourage portability and communicability of different softwares developed on it.

The implementation of all the characterizing dimensions of a tutoring system are benefited from such an advance in software platform.

The Opportunities

The recent advent of software technologies, if treated as a conglomerate of the aforementioned software products and techniques, has offered numerous opportunities for CAI:

- On CAI Capabilities. It means more enhanced CAI capabilities: from text-based display to drawings to graphics animation; from rigid information access to detailed elaboration on subject knowledge; from programmed branching logic to more adaptive or nearly intelligent tutoring.
- On CAI Authoring. It means more quickened CAI development. With multi-linking (or called multi-hooking) of software, concurrent development of courseware is also made possible. Moreover, the user-friendliness of authoring and expert system software also alleviate the expertise problem that previously mentioned.
- On CAI Architecture. It means we can experiment for more different ways of structuring a tutoring system for more versatility, modifiability and modularity. This is particularly important to ITS development as there is still no consensus on the architecture of an ITS [Winkels, 1990].
- On CAI Operation. More friendly software, more verstaile operations due to the use of WYSIWYG interface and open software platform have also encouraged the development, utilization and (possible) reuse of courseware.
- On Cost. With shortened development time, more versatile tools availableand more graphical support on multi-linking platform, reduction in CAI development cost is anticipated.

A Precalculus Courseware

Description of the Previous System

Some years ago, as an experiment on CAI, we have developed a precalculus courseware for F.4 (or grade 10) secondary students using a conventional authoring system, PROPI [ASYS, 1988]. Conventional frame approach is adopted and graphics and interactive screens are built such that the courseware would be interesting to its audience.

Basically it's a comprehensive course on precalculus consisting of ten lessons covering the following topics:

i) Function - explicit and implicit functions.
ii) Increment notation - the use of the delta sign.
iii) Limit - basic operation.
iv) Derivatives - definition and application.
v) Differential rules - some basic rules.
vi) Differentiation - on Trigo functions.
vii) Higher differential - concept of 2nd derivative and general notations for higher.
ix) Extremum of functions - tangent of slopes; monotonicity of functions; point of inflexion; calculating for maximum and minimum.
x) Curve sketching - basic sketching of the graph of a function.

With the CAI treated as directed graph, lessons are viewed as nodes in the graph. Some intermediate checkpoint or milestone nodes are introduced so that the learner or student's understanding on the topics can be testified against some questions accompanied with the nodes. Based on the feedback answers, the next traversed node of the student is then determined. (This original courseware is really a typical so-called programmed branching CAI.)

This courseware has been tested satisfactory with its functionalities. As more software technologoies are emerging, it would be best in investment viewpoint if the courseware could be improved or extended for higher performance and adaptiveness instead of being scraped. Lest, our previous efforts in developing the courseware, including the graphics and screen designs, etc. would be wasted.

An Extended System Architecture

Previously, Wu has proposed the *dimensional extension* paradigm [Wu, 1992] in revamping traditional CAI for more intelligence. This approach is also adopted in our incorporation of new software technology in rejuvenizing the software. Basically the algorithm for the approach is:

ALGORITHM (dimensional extension):

i) Index every nodes in the CAI.
ii) Resolve all links between nodes, or index links of the CAI graph in a table, the link-table. (This link-table therefore captures the CAI's instructional flow.)
iii) Translate the link-table into a rule base (the link-table can be viewed as a kind of decision table).
iv) WHILE there is checkpoint node
    DO imitate the checkpoint nodes' links and relations with other nodes on the rule base, build more rules to the knowledge base if necessary;
    relinquish the checkpoint nodes' links
    (essentially this step dissolves and transforms all relations of the checkpoint nodes into the rule base)
v) Re-think on the instructional flow of the CAI for better adaptiveness, ignoring the limitations posed by nodes at the moment
vi) Re-build the link-table based on step v), establish more rules, amend the related nodes (including checkpoints or non-checkpoints), or add more nodes if necessary
vii) Stop or go to step v) for more refinement

Essentially, an extended system architecture is formed by amalgamating the existing CAI architecture with an additional orthogonally constructed rule base. Thus, dimensionally the CAI is extended.

Results

As a start, the new courseware is built on PC with the DOS environment. M1 [Teknowledge, 1986], a rule-based expert sytsem shell is employed for establishing the rule base. Parameter files are used as the communication tools between PROPI and M1 for the deduction of instructional flow. Around thirty-five rules are constructed in the initial re-furbishment and enhancement phase. The courseware also appears to be more intelligent. However, due to file I/O (input-output), significant time is also induced. The effort spent in establishing the links between the knowledge base and the CAI nodes is also more than anticipated.

Currently, we have entered into the second phase of the courseware enhancement by porting the software on the Windows platform whereby multi-linking between different softwares is facilitated. An initial re-work indicates that previous problems due to link building are alleviated. The open software platform does facilitate the enhancement a lot as it more or less provides a uniform infrastructure for development. We have also planned to introduced more hypertext type information elaborativeness capability to the courseware. Hopefully more encouraging result could be reported in the future.

Conclusion

Indeed, recent advances of software technologies have relaxed the challenges of the development and use of CAI from drudgery. Yet, as our examples demonstrated, it's only through proper integrating of software together with a well coordinated and supported software infrastructure can the opportunity be exploited.

References

ASYS (1988). *PROPI Manual v.3.0.* ASYS Computer Systems, Washington, USA.

Barker, P. (1987). *Authoring Languages for CAL.* London:Macmillan.

Bonar, J.G. (1985). Bite-sized Intelligent Tutoring. *ITSG Newsletter 85-3.* Leraning Research and Deve Center U of Pittsburgh, Pittsburgh Pennsylvania.

Chang, S.K. (Ed.) (1990). *Principles of Visual Programming Languages.* NJ: Prentice Hall.

Conklin, J. (1987). Hypertext: An Introduction and Survey. *IEEE Computer.* Sep 1983. pp.17-41.

Edwards, A.D.N. and Holland, S. (Eds.) (1992). *Multimedia Interface Design in Education.* Berlin: Springer-Verlag.

Finzer, W. and Gould, L. (1984). Programming by Rehearsal. *Byte,* Vol.9 No.6, Jun 1984, pp.187-210.

Harel, D. (1992). Biting the Silver Bullet: Toward a Brighter Future for System Development. *IEEE Computer,* Vol.25 No.1, Jan 1992. pp.8-24.

McCalla, G.I. (1990). The Central Importance of Student Modelling to Intelligent Tutoring. *Proc. of NATO Adv Res Workshop on New Directions for ITS.* Sintra, Portugal, Oct 1990. pp.107-131.

Mettrey, W. (1991). A Comparative Evaluation of Expert System Tools. *IEEE Computer* '91 Feb, 19-31.

Microsoft, (1985). *Microsoft Windows Manual v.2.0.* Microsoft Inc.

Price, R.V. (1991). *Computer-Aided-Instruction: A Guide for Authors.* Belmont, CA: Wadsworth.

Richards, T., Webb, G. and Craske, N. (1988). Object-oriented Control for Intelligent Computer Assisted Learning Systems. In *Artificial Intelligence Tools in Education.* Ercoli, E and Lewis, R (Eds.), Elsevier.

Schneiderman, B. (1983). Direct Manipulation: A Step Beyond Programming Languages. *IEEE Computer.* Aug 1983.

Self, J.A. (1974). Student Models in Computer Aided Instruction. *Int J of Man-Machine Studies,* No.6, 1974. pp.261-276.

Shlechter, T. (Ed.) (1991). *Problems and Promises of Computer-Based Training.* Norwood, NJ: Ablex Publishing.

Teknowledge (1986). *M1 Reference Manual.* Teknowledge, Inc. USA.

VanLehn, K. (1988). Student Modelling. In Polson, M.C. and Richardson, J.J. (Eds.). *Foundations of Intelligent Tutoring Systems. Hillsdale,* NJ:Lawrence Erlbaum Asso. pp.55-78.

Wong, S.C.H. et al. (1989). An Interactive Speech-Enhanced Computer-Assisted Putonghua (Mandarin) Learning System: A Prototype. *Proc. of Microcomputers in Education.* Hong Kong Association for Science and Mathematics Education. July 1989, pp.C-31-35.

Winkels, R. and Breuker, J. (1990). What's in an ITS? A Functional Decomposition. *Proc of NATO Adv Res Workshop on New Directions for ITS.* Sintra, Portugal, Oct 1990.

Wu, A. K, W. (1992). Embedding Intelligence to Traditional CAI (Computer-aided-instruciton) with Minimal Cost. *Proc of IITT Int Conf on Expert Systems Application Exper-Sys.* Oct, 1992, Houston, USA. pp.59-64.

Wu, A. K. W. (1993a). Paradigms for ITS (Intelligent Tutoring System). *Pro of IEEE TENCON in Computers, Communication and Automation,* Oct 1993, Beijing, pp.96-99.

Wu, A. K. W. (1993b). A Taxonomy of Tutoring Systems. *Proc of Int Conf on Computers in Education.* Dec 1993, Taipei, Taiwan.pp.187-192.

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Teaching a General Education Mathematics Course Using Distance Learning Strategies

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Abstract: An experiment in using distance learning strategies to deliver two general education mathematics courses is presented. The courses, which use analytical methods to solve real-world problems, have a nonhomogeneous student body possessing a wide variety of learning styles and abilities. The authors use distance learning supported by email, electronic conferencing, electronic document transfer, and computer simulations to provide a learning environment in which each student can learn at his or her own pace.

Introduction

We describe a two-year experiment in delivering a general education mathematics course via distance learning strategies. The experiment is being conducted in the Plan for Alternative General Education (PAGE), now in its tenth year at George Mason University. PAGE is a four-semester, 45-credit integrative set of interdisciplinary courses that is designed to replace the "cafeteria-style" of general education requirements.

One of the underlying beliefs of the PAGE program is that students must "learn-to-learn." Too often traditional methods of course delivery do not meet this goal. Especially in mathematics courses, it is often the case that students are "lectured" at with little or no opportunity to ask questions or get feedback.

In our experiment we provide this feedback through a variety of distance learning strategies. We also use the feedback received from each student to customize his or her learning experiences.

The Setting

Our experiment takes place in selected sections of a two-course sequence titled "Analysis and Solution of Quantitative Problems I & II (PAGE 125 & PAGE 225)." These courses aim at helping students develop problem solving and reasoning skills and not just the traditional transfer of knowledge on specific techniques. The two courses are taken in sequence and target 2nd semester freshman (PAGE 125) and 1st semester sophomores (PAGE 225) who have no plans to choose a career in the sciences or mathematics.

Many of the students make clear from the beginning their fear (if not distaste) of mathematics. In addition, the students come to the courses with very diverse backgrounds in mathematics. The majority have had exposure to two years of high school algebra, some (maybe 20%) have taken geometry and trigonometry, and a much smaller percentage have taken a pre-calculus course or even a calculus course while in high school. Hence one of the goals of the courses is to overcome feelings of anxiety, while at the same time providing an atmosphere of learning that is challenging to the better prepared students. The primary way this is done is by providing a self-paced learning environment that maintains continuous contact through electronic communications. We provide each student with his or her own opportunity to make discoveries, ask questions, and be given individualized hints or support.

The self-paced learning environment is created through a variety of teaching strategies. Among these are: extensive two-way email contact; use of computer assisted exercises that support the "learning

through discovery" process; a limited amount of classroom presentations; and one-on-one, in-person discussions, when absolutely needed.

Early Difficulties and Solutions

We have found that the current complexity of electronic communication is often a major hurdle for some of the students. Besides delivering course content, another task during the first couple of weeks of each course is the re-training of our students in the areas of email, word processing and file transfer. Although our students have completed a computer literacy course, "Computers In Contemporary Society,"(PAGE 120) prior to coming to our courses, we find that a number of them have forgotten the "mechanics" involved in email and file transfer.

Because PAGE 125 is offered in the spring and PAGE 225 is offered in the fall, re-training in computer skills is required in both courses.

One way this re-training is provided is through a self-paced, computer based tutorial program that reviews the "fundamentals." The tutorial program, GMUCOM, developed by the first author, is a custom designed software package that teaches the use of VAX email, uploading and downloading of files and file management under the VMS (VAX) operating system. While the program is effective in reviewing and teaching the basics, it alone can not transform students who are used to studying in isolation into "partners in learning."

The authors have found using email as a "chatting" device to be an excellent way to develop a rapport with students. At the same time it forces them to re-familiarize themselves with the basics of email and eventually file transfer.

During the first week of his PAGE 125 class (Spring 94), the second author exchanged more than 200 messages with his 20 students. Initially, most of the messages were only marginally related to the class and concerned issues of interest to the students ranging from discussions of science fiction movies to more serious forums on musical topics. By the third week of classes, even the less enthusiastic students had become heavy users of electronic communication. Also, the natural increase in the complexity of their messages motivated student interest in using more sophisticated word processing techniques. (Since they sent email through our VAX mainframe computer, they did not have available to them a user-friendly, menu driven editor. Instead, they did their word processing on a PC, saved their work in ASCII format and uploaded it to our VAX and then emailed it to the instructor or their classmates.)

The Mechanics

The mechanics of the courses involve a number of different computer tools and techniques. These include a programmable calculator (HP32Sii), email, file transfer of submitted and graded work, the use of the statistics program MINITAB to simulate random sampling and analyze data, and VAX Notes which is used to maintain a "class conference."

VAX Notes provides a bulletin board-like conferencing system. It is here that our students get their homework assignments and class notes. The program runs on our VAX mainframe and is accessible to students from many locations on campus as well as through dial in access from their home or dorm room. (Many of the students who elect to take these courses have their own computer and modem.)

Besides posting notes and assignments to the conference, the instructors can post anonymous examples of course work completed by a student or a "project team" of students. Sometimes this work is selected because of its quality; other times works of previous students are posted and the current students are asked to critique the work and or improve it.

Course Content: Some Examples

One of the learning modules of PAGE 125 involves trying to understand how objects accelerate as they fall. This section of the course, referred to as the "gravity" section, involves a hands-on experiment in which students gather data to estimate the speed at which an object will hit the ground if it is dropped from 100 feet.

First students learn about the historical setting of the problem: Aristotle gave philosophical arguments for why heavier objects fall faster than light ones; Galileo gave birth to modern science by insisting that the motion of bodies could only be understood through measurement and experimentation.

Next our students actually gather data on how long it takes an object to fall several given distance. Then they graph this data with the Distance as the horizontal axis and Time as the vertical axis. Several different transformations are performed in attempt to "see" how to interpret the data. For example, students plot Time versus Distance, Time versus log of Distance, and Time versus square root of Distance. When they plot Time versus square root of the Distance they get a graph in which the data appears to lie on a straight line. This is the motivation for applying the technique of linear regression that was learned in an earlier course module. Next students use their programmable HP32Sii calculator to perform a "least-squares" fit of the data. The results of this "fit" are used to derive a formula that gives the time T it takes an object to fall D feet. Using this formula they derive another formula that gives the speed an object is falling after it falls a given distance.

In essence this "gravity" section is an introduction to the concept of the limit that is studied in calculus. Since our students are not science or mathematics majors, they are for the most part, ill-prepared mathematically for such an investigation. However, we are quite successful in getting them to understand the material through the use of customized individual feedback and support.

For example, although the data collection is rather easy, many of the students have trouble with correctly graphing the "transformed" data and carrying out the "least-squares" fit. In addition, the simple algebra steps involved in some of the formula derivations are often great stumbling blocks.

Students are asked to leave their hand-drawn graphs in the PAGE Office and to check their email for instructor comments. Each student is notified if there is a problem with his or her work and is given a chance to resubmit it. Next the algebra involved in derivations is reviewed and explained through a series of emailed questions that must be answered by providing both the required algebraic computations along with written explanations of how the various steps are related. More detailed explanations and extra work is emailed to those students who need it.

Since our courses are designed to develop problem solving skills, after students master the concepts involved in the "gravity" problem, they are given an opportunity to apply what they have learned to a few similar problems. Some of these new problems are very close to the original in level of difficulty and computations involved while others are more sophisticated required hardware or software support.

Among these examples are the study of the motion of a simple pendulum, and the study of the harmonic motion of the diameter projection of a uniformly moving point on a circle. The study of the uniformly moving point can be done by carefully looking at the second hand of a wall clock, and its projection on a fixed diameter of the circular face of the clock. While it is rather easy to take the measurements needed to study the motion of the pendulum, there are some definite measurement difficulties that make the second problem rather cumbersome. We are currently preparing a software package that simulates the clock and the uniformly moving point related to the motion of the second hand's projection onto a diameter of the circular face.

Another course module is titled "charting the earth". In this module students learn how to find the distance between two cities on the same circle of latitude or line of longitude. They are led to the correct formulas by being asked to examine related, but easier problems. For example, they start with trying to find the distance between two points on a circle. Accomplishing this involves understanding the angle made by the radii that connect these points to the center of the circle. This leads to the need for an understanding of how cartographers "label" points on the earth. This is precisely where some students begin to have difficulty.

Drawing a rough sketch of the earth, including the appropriate lines of longitude and circles of latitude, proves to be a difficult task for many of the students. One attempt to augment student spatial intuition involves a styrofoam ball. The ball is sliced in a way that reveals the angles used to represent the position of a city on the earth—the longitude and latitude measurements. We are also developing a PC-based program that will allow students to enter the longitude and latitude of a city and have displayed on the screen the corresponding angles that "represent" its location.

Drawbacks

Our greatest difficulties with delivering PAGE 125 and PAGE 225 as distance learning courses center around technological issues. Currently students cannot easily create and email graphics files or files that include voice overlays. Because of this, when teaching topics such as "charting the earth" we sometimes find it necessary to meet with some of the students face-to-face. Another problem related to technology is the difficulty in delivering course notes and materials such as quizzes or exams. Our students eventually learn the complex process of extracting a copy of the day's course notes from the class VAX Notes conference, downloading the copy to their PC, and then printing it out. However, the process is so time consuming that student often opt for using "PrintScreen" to get screen prints of class note as they view them on the screen. Often this results in course notes that are at best disorganized, and too often in notes that are incomplete. We are currently experimenting with delivery of course notes via other means such as a gopher or mail program that will "transparently" place emailed information on a student's PC.

DEMONSTRATIONS/POSTERS

Computer Assisted Instruction in Mathematics

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Overview:

Over the past five years, the Western Interprovincial Mathematics Consortium (Alberta, Manitoba, Saskatchewan and British Columbia) has been developing secondary school mathematics learning resources for Distance Education. These CAI programs deliver sound pedagogy through an instructional model which uses animation, colour, sound and interactivity to create an exciting and motivating learning environment for students.

Content:

The CAI programs, packaged on CD-ROM, are available for all levels of high school mathematics and cover most topics including calculus. Each course offers tutorial and test components and has the potential to provide individualized or remote instruction, vary methods, manage testing and record keeping while engaging and challenging all learners through interactive, animated multimedia presentations.

Instructional Design:

The courseware is being developed using Authorware Professional, a visual programming tool which enables educators who have little or no programming experience to create multimedia learning resources for teaching and learning. Each course/program includes:

- diagnostic / placement assessment
- course maps (content)
- navigational routers (sequence guides)
- computer administered test banks, review, practice, summative evaluation
- instructional / tutorial text
- on-screen help and feedback
- interactivity, animation and graphic sequences
- student achievement and records management profiles (individual, class)
- performance levels established by instructors
- alternative learning resource database

Audience:

Although the target markets for these packages were Distance Education centres, interest has been growing in regular, traditional classrooms and Open Learning Agencies from teachers who desire an exciting, new approach to instruction.

Demonstration:

This demonstration will use High School exit level Math (BC Math 12) to show both the power and the content of our products. The session will highlight the quality and variety of instructional design, focusing on the effective use of animation, colour and interactivity to motivate and teach as well as the navigational tools which facilitate progress through the content and empower the users. Finally, the demonstration will feature the powerful graphics components which allow users to investigate abstract concepts through graphic manipulation. Unique "Explorers" have been developed for Polynomials, Trigonometric Functions, Logarithms and Exponents. This demonstrations will also feature the newest graphic Explorers for Statistics and Calculus as well as Linear and Quadratic Relations.

Using Scientific Visualization to Do Science and Mathematics in the Classroom

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A long-standing goal of members of NCSA's Education Group has been encouraging teachers to "bridge the gap" between classroom science and the kinds of scientific research done by professional mathematicians and scientists by using high performance computing (HPC). Students understand the value of science better when they see real-life applications of the concepts they are learning.

Many simulation programs available for classroom use permit students to examine interesting concepts, but the results only roughly and symbolically approach reality. Several interactive simulation programs developed at NCSA offer higher fidelity or closer approximations of reality. These simulations have been adapted from simulations used by scientists working at or with NCSA and allow students to use real scientists' tools to gather, visualize and analyze real data. Not only does this allow students to study exciting questions never before possible in a K-12 classroom, but students are asking and helping to answer questions that intrigue even today's scientists. Galaxsee, Simsurface, ChemViz, and Fractal Microscope are interactive tools for scientific inquiry that combines the power of a supercomputer with the user friendly environment of the Macintosh.

GalaxSee is designed to help young scientists investigate the as yet unresolved question, "How do galaxies form?" Although this question is typically studied only by research scientists, this combination of NCSA visualization applications written for the Macintosh with the accelerated calculations on the Cray-YMP supercomputer invites even an elementary school student to ask the questions that contemporary scientists are asking--allowing real students to do real science in real classrooms.

In the GalaxSee program the user specifies a number of stars, which the computer initializes in a random spherical distribution. The user then specifies the masses and velocities of these stars, and the computer takes it from there. At each time step, the galaxy program simply calculates the force on each star due to all the others and then updates each velocity and position. The NCSA DataScope display window displays three views of the galaxy--each view along the X, Y, and Z axes. The stars are represented as colored dots on the screen, with the colors corresponding to the number of stars along the line of sight.

SimSurface demonstrates two uses of scientific visualization: it animates a set of advanced numerical algorithms allowing a student to understand both the *process* of computation and its *result*. SimSurface demonstrates two common computational techniques: simulated annealing and the relaxation method. *Simulated annealing* is an often-used method for finding global maxima and minima of complicated or multi-dimensional functions. The problem being solved in SimSurface is a minimization of potential energy. The question we are trying to answer is: given *n* stationary electrons confined to a 2-dimensional surface by four negatively charged walls, what arrangement of electrons has the minimum total energy and is thus the configuration preferred by nature?

The user enters parameters not only dealing with the initial conditions of the surface and electrons but can also adjust "knobs" for values that control the cooling process used by the simulated annealing algorithm. The program also displays the process of the annealing at user-controlled intervals, since it is also instructive to watch as the minimization takes place. Once the system has reached a minimum energy (to within a specified tolerance), the **relaxation** method is used to solve LaPlace's equation.

ChemViz enables advanced chemistry topics to be addressed in the high school curriculum by harnessing HPCC technologies. The user runs *Boogie* on the Macintosh (or PC) and selects from the periodic table the constituent atoms for the molecule to be computed and visualized. A sequence of images can also be selected to allow for simple animations. Then the data file created by Boogie is sent by modem or over the Internet to a remote supercomputer which is running *NCSA Disco* , a chemistry solver that computes electron densities. The data files created by Disco are then sent back to the user to be visualized using *NCSA Collage* or other visualization tools such as Spyglass Transform or Dicer (which allows three dimensional animations). With this approach, the students and teachers using the ChemViz materials become apprentice scientists, rather than passive learners.

The Fractal Microscope is an interactive tool for exploring the Mandelbrot set and other fractal patterns. Sudents and teachers from all grade levels can engage in discovery-based exploration, zooming in on any area of the Mandelbrot Set fractal. Users can continue to zoom in, allowing infinite magnification of the "microscope." This program can be used to introduce a wide variety of topics, including scientific notation, coordinate systems and graphing, complex numbers, self-similarity, infinity, convergence and divergence.

The Development and Validation of a Computer-administered, Simulation-based Test of Integrated Science Processes for Pre-service Teachers

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Since the 1960s the focus of science education has been shifting from science as a body of knowledge to science as a human endeavor that uses processes to generate knowledge. The development of instruments able to evaluate the processes of science, however, has lagged behind the implementation of process-related curricula. From the 1970s through the 1980s the development of more than a dozen tests of science process skills still left some gaps in providing for appropriate testing at all levels.

Little effort has been directed towards measuring the ability of those who will teach the process skills--elementary science teachers. Test development has also not taken advantage of computer technology. Finally, the majority of test developers have not focused on providing multiple strands of evidence of the valid interpretation of scores generated by their instruments. More than half of the commonly known science process skills tests provide only evidence of content congruence from the use of panels of science education experts. Although content congruence is requisite, it is not sufficient to validate the use of an instrument.

This study was undertaken to address some of the shortcomings of efforts in the development of tests of science process skills by developing and providing initial evidence of validity of a computer-administered, simulation-based test of integrated science process skills for pre-service elementary teachers (CTISP).

The CTISP is an interactive computer program consisting of a set of general directions, a practice section and a 5-part test. Each part of the test is based on a scenario describing a problem that is the result of a single factor. For example, one scenario describes two pans of liquids evaporating at different rates while another compares the stretch length of two rubber bands. Each part of the test is composed of a question section, an experiment section, and an answer section. An examinee may move among the sections in any order. In the question section, the examinee can receive an answer to any of 10-12 questions related to factors that could account for the problem. In the experiment section, the examinee may select to change 10-12 factors singly or in combination. The impact of the selected change appears on a summary screen. The examinee may run as many "experiments" as desired. In the answer section, the examinee may select any of 10-12 possible reasons for the problem. When the examinee selects the final answer(s), that test part ends.

The test score results from the number, type, and sequence of actions. For example, selecting two redundant questions or changing more than one condition at a time in an experiment produces negative points. On the other hand, running an experiment to check a condition which data from the questions supports as a possible factor or selecting an answer supported by question and experiment data produces positive points. The program captures each keystroke. A scoring scheme is then applied to these actions to produce scores.

The initial part of the study was the design and production of the instrument. The target skills included the ability to identify variables appropriate to a given problem, to hold appropriate variables constant during an experiment, to draw valid conclusions from data, and to use the integrated science process skills in an effective order. An iterative process using multiple panels of experts was used to develop the instrument. Pilot testing of the instrument to obtain item characteristics was conducted using 35 volunteer pre-service elementary teachers. Formative data from the pilot testing was the basis for revising both the program and computer screens and for selecting the scenarios demonstrating the highest internal consistency and instructional sensitivity.

A field test with 200 pre-service elementary teachers is currently being conducted to estimate the reliability, as measured by internal consistency, and to collect evidence of the valid interpretation of the scores. Evidence for validity will be derived from four sources--the actual test-development process, a comparison of scores of an instructed group and a pre-instructed group, the analysis of the correlation between scores on the CTISP and on a paper and pencil concurrent measure, and an exploratory factor analysis to investigate the underlying structure of the test.

If evidence of reliability and validity can be obtained, this instrument could be used as a viable assessment alternative or companion to both research projects and paper and pencil tests.

Legitimate Peripheral Participation through Electronic Communications: Fostering Community in Classrooms.

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There is increasing interest in researching the social aspects of learning. One stance on situated learning is the Legitimate Peripheral Participation (LPP) learning theory of Jean Lave and Etienne Wenger (1991). LPP situates both success criteria for, and outcome of the learning process within the community.

Communities of Practice exist in a dialectical relationship; a community and its practices are mutually constitutive. A community's rhetorical and discourse practices are formed through the joint interaction of the members of the community. At the same time, their communicative practices form an essential aspect of the group's collective identity.

LPP is based on a notion of trajectories of participation. An example of such trajectories can be found in a community of computer mail users. First, new users are nothing more than observers of the interactions of others on the electronic discussion group. Eventually, they begin to have private exchanges with other members. Finally, they begin to have public discussions and, if accepted by the others, can become a regular part of the discourse community.

Computer mediated communication can play a major role in fostering community within a classroom setting. The site for our own investigations was a course on computer networks and communication, taught by different instructors during the 1992/93 and the 1993/94 academic years.

LPP suggests that teaching objectives can be fostered through social interaction. However, the social setting for that learning cannot be imposed upon by an outsider. Our context provides us with a contrasting set of conditions under which to consider this phenomenon. Previous offerings of the sequence had the students forcibly placed into group work situations, while this year had no such requirements.

The result was a very different social organization. In both years, the courses had a significant number of functional groups. However, in the 93/94 year all groups were self organizing, with only logistical support from the instructors.

The role of electronic mail as mediator in the process can be seen through a second comparison. The second quarter 93/94 course was taught in parallel with a course on technological change. Both courses shared the same instructor and course organization. However, the second course did not include electronic mail for the students. In that course only a very small fraction of the students choose to complete their projects in groups. We will argue, with Lave and Wenger, that electronic communications served as the critical medium in which the practices of this community were embodied. It is through those practices that the community became constructed and defined.

Presented here is a qualitative analysis of the social interactions using computer mail, interviews, demographic data, and ethnography. We provide a picture of the social interactions that occur when electronic mail is provided as a medium of communications and serves as the focus of community practices. The case will be made that electronic mail can serve to foster communities of practice in classroom settings without the need for explicit group organization

Reference

Lave, J., & Wenger, E. (1991). Situated Learning: Legitimate Peripheral Participation. Cambridge, Ma: Cambridge University Press.

Infectious Mathematics: Modeling on the Graphing Calculator

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One of the ultimate goals of education is to prepare young people to function confidently and knowledgeably in real-world situations. Unfortunately, the relationship of mathematics to the study of real phenomena is rarely included in the everyday educational agenda. There is plenty of opportunity and compelling necessity to design and implement context-driven instructional activities where students investigate authentic problems through multidisciplinary and/or technological approaches. By applying the tools of mathematical modeling, high school students can experience firsthand the interplay among mathematics, the natural sciences, the social sciences, technology, and human affairs.

The current AIDS epidemic is an important public health issue that can, and should, be investigated in an interdisciplinary arena at the secondary level. Advances in graphing calculator technology allow explorations into epidemic modeling that are normally calculus-based. Differential equation models can be represented using difference equations so that they become accessible to algebra students. An interactive AIDS model, based on simplifying assumptions, can be devised by students for a homosexual population subdivided into three groups (susceptibles, HIV+ without AIDS, and AIDS) where the spread of the virus is described as a function of time. Using the recursive function mode of the calculator and data lists, the course of the epidemic can be tracked and analyzed graphically, then interrogated by varying the initial values of the system's parameters. Adjustments to the initial population size (P), the normal death/growth rate (D), the rate of developing AIDS after HIV+ (R), the probability of HIV+ infection by sexual contact with an infected individual (H), the average number of sexual contacts between partners (C), or the average number of new sexual partners per year (N) will generate different epidemic scenarios and different possible social intervention policies. The system of difference equations below describes the population dynamics between the susceptible (U_n) and HIV+ (V_n) groups in a deterministic AIDS model (figure 1).

$$U_n = U_{n-1} + D(P - U_{n-1}) - HCN\left(\frac{V_{n-1}}{U_{n-1} + V_{n-1}}\right)U_{n-1}$$

$$V_n = V_{n-1} + HCN\left(\frac{V_{n-1}}{U_{n-1} + V_{n-1}}\right)U_{n-1} - (R + D)V_{n-1}$$

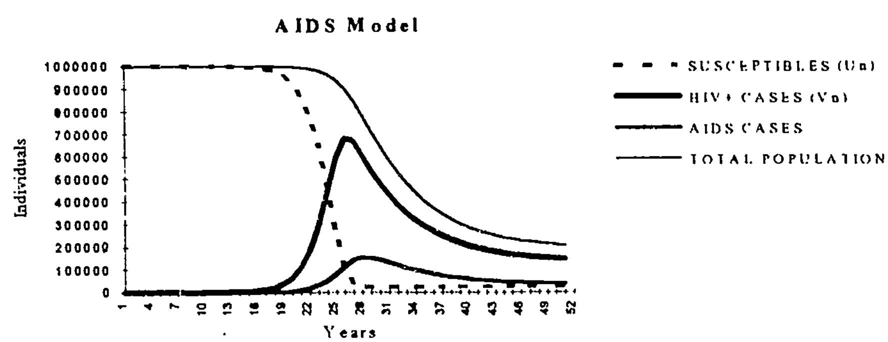

Figure 1. The solution of the AIDS model defined by the recursive equations above with the initial conditions $P = 1000000$, $D = 0.02$, $H = 0.025$, $C = 1.5$, $N = 25$, and $R = 0.125$.

Reference

Hyman, J.M. & Stanley, E.A. (1988). Using mathematical models to understand the AIDS epidemic. *Mathematical Biosciences*, 90, 415-473.

GraphLab:
Software for Teaching Students to Think About Graphing

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Program Description and Assessment

The tasks of graphing can be divided into two major areas: graph construction and graph interpretation. Graph construction requires students to know several rules about assignment of variables to axes, choosing a range of values for each axis and dividing that range into intervals, and placing data on the graph. Graph interpretation involves less clearly defined tasks and often cannot be expressed by fixed rules. We designed a tutorial called GraphLab to teach basic principles and skills of graph construction and interpretation.

We identified four graphing difficulties common among college students: choosing the appropriate scale, finding the relationship between two variables by drawing a best fit line, identifying error in data, and understanding how the source of error influences our ability to reason about that data. GraphLab is divided into four sections: scaling, best fit lines, least squares, and error. In each section students are presented with principles of graphing illustrated with graphs of classic findings in the physical sciences. For each principle, one graph is plotted in accordance with the principle, and one graph is plotted in violation of the principle. A dialogue box asks students reflective questions to encourage summarization and evaluation. Following the examples, students practise the current principles and skills by performing the relevant graphing task for several different graphs before moving on to the next section.

We implemented and evaluated GraphLab in a freshman chemistry course at UCLA. The class was randomly divided into an experimental group and a control group (92 and 91 students, respectively). A pre-test ascertained that the samples were roughly equivalent at the beginning of the quarter. Both groups received a handout of guidelines for graph construction and interpretation. The experimental group did GraphLab and the control group did not. Students in the experimental group spent an average of 45 minutes doing the tutorial. The post-test administered at the end of the course consisted of two tasks, scaling and best fit, and each involved several subtasks. The best fit task was designed to assess students understanding of error sources in data. Students were asked to draw the best fit line for a plotted set of data and calculate the slope of the line. The data they were given contained a systematic error. The best fit lines drawn by students were categorized into two groups -- lines that were actually the line predicted by theory, which might reflect the assumption that all deviations in data points from the line are due to random error only, and lines that more accurately bisected the data, which might reflect an assumption that the data contained systematic error as well. We also asked students to state any assumptions made about the data and scored which error sources they identified (random, both random and systematic, or none).

Results and Discussion

The experimental and control groups improved about equally on the scaling task from pre-test to post-test. Several differences appeared on the best fit task. Students who did GraphLab were more accurate at drawing a best fit line than students in the control group. The control group more frequently drew the theoretical line rather than a best fit line, and more often identified the line they drew as the theoretical line. The experimental group mentioned random error only, and both random and systematic error. more frequently than the control group. There was no significant difference between groups on accuracy at calculating the slope of the best fit line.

We conclude that the current version of GraphLab does help students learn to select appropriate scales and to draw a line to fit data. However, the program was less successful in teaching students the concept of error sources. The increased identification of both random error only and random and systematic error indicates that the tutorial increased their awareness of error sources but did not reliably help them to distinguish the two. Another indicator that the experimental group learned how to draw a best fit line, but not to understand how error in data causes a best fit line to differ from a theoretical line, is that the greater accuracy of the best fit lines drawn by GraphLab students was not accompanied by greater accuracy at finding the slope of the line. The cause of this discrepancy may be that the first two tasks are both essentially construction tasks, requiring students to learn a simple rule and apply it reliably, while the last task is an interpretation task that requires conceptual understanding, not just rule application.

Longitudinal Effects of Calculator Implementation on Students' Attitudes Toward Calculator Use

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Many professional organizations in education have encouraged mathematics educators to reform the curriculum and incorporate more technology into the classroom instruction and activities. The Professional Standards for Teaching Mathematics (NCTM, 1991) and the National Research Council (1989) have recommended the implementation of calculators and computers into middle school mathematics. Some researchers have demonstrated the effectiveness of calculators and computers for improving students' mathematics achievement (e.g., Bitter & Hatfield, 1992, 1993; Hambree & Dessart, 1986). Most of these studies, however, have focused on the implementation process and the positive effects of technology on students' cognitive outcomes. Relatively few studies have examined the impact of calculator use on students' affective domain or specifically examined how students' attitudes toward calculators change over time. Since some studies have found that students do not always have positive attitudes toward calculators (Bitter & Hatfield, 1992; Huang, 1993), it is important to see if their attitudes are stable over time or if they can be improved after they have used them. Furthermore, most of these studies examined students' attitudes at one point in time or at best changes between the beginning and end of the school year. Very few studies have examined whether students' attitudes change over a prolonged period of time. Consequently, the objective of the present study is to provide such information to further teachers' understanding of the long-term effect of implementing the use of calculator in a mathematics curriculum. More specifically this study addresses three research questions:

a) What are students' attitudes toward the use of calculators at the beginning of middle school?

b) What are these students' attitudes toward the use of calculators after calculators have been implemented in mathematics for nearly two years?

c) Are there significant changes on students' attitudes toward the use of a calculator?

Methods

The participants in the present study were 1,242 middle students from a multi-ethnic school district located in a metropolitan city in the South Central region of the United States. About 48% of the students were male and 52% were female. Nearly 22% of them were Hispanic, 21% black, 31% white, and 26% Asian.

The instrument used for this study is the adapted version of SUPAI student calculator survey (Bitter & Hatfield, 1992). It consists of 23 items on a four-point Likert-type scale. A mean value of "4" indicates that the student responded "very true" to the item, while a mean value of "1" indicates that the student responded "not at all true." The instrument has been found to be reliable and valid in previous studies. In the present study, the alpha reliability coefficient was found to be .78 for the initial survey and .80 for the final survey.

All the students in the present study were issued a pocket calculator when entering the middle school, and all the middle school mathematics teachers in the district received at least 12 hours of in-service training on how to integrate the calculator into the current school curriculum. The survey was administered twice to the same students during mathematics classes by experienced researchers: the first one in October of their sixth grade year, and the second one in May of their seventh grade year.

Results

Descriptive statistical results indicate that students had favorable attitudes toward the use of calculators when entering middle school. Over 80% of the students responded "very true" or "sort of true" that (a) it is important that everyone learns how to use a calculator; (b) calculators make mathematics fun; and (c) mathematics is easier if a calculator is used to solve problems. Students' attitudes toward calculators became increasingly favorable as

a result of teachers' integrating calculators in mathematics instruction. At the end of their seventh grade year, over 90% of them indicated that they knew how to use a calculator very well, and had no difficulty reading the calculator screen. About 85% of them also indicated that (a) mathematics is easier if a calculator is used to solve problems; (b) it is important that everyone knows how to use calculators; (c) calculators are useful for solving fraction problems; and (d) using a calculator helps in mathematics work.

Correlated t-test results reveal that there were significant changes in students' attitudes toward calculators after calculator use has been introduced in mathematics for nearly two years. Students' attitudes became more favorable in 13 indicators, including using a calculator makes one try harder in mathematics ($p<.001$). Significantly fewer students responded that the calculator will cause them to forget basic arithmetic facts or how to do basic computational skills or to decrease their estimation skills. Significantly more students responded that (a) using a calculator helps them with their mathematics work; (b) calculators are useful for solving fraction problems; and (c) using a calculator to solve money problems is not confusing. However, students' attitudes became less favorable toward other indicators, for example: (a) I feel smarter when I use a calculator; (b) calculators make mathematics fun; and (c) mathematics is easier if a calculator is used to solve problems.

Discussion

The results of the present study suggest that, in general, students had positive attitudes toward calculators. The results further indicate that after mathematics teachers integrated the calculator into their classroom teaching and learning process for nearly two years, the cohort group of students showed significantly more positive attitudes toward its usage. The longitudinal effects were especially obvious in attitudes associated with reducing students' concerns about possible negative effects of using calculators in mathematics. As students gained practical experience and familiarity with using calculators, they had better sense of what calculators can do and cannot do. They were assured that calculators help them with their mathematics work and indeed motivated them to try harder in mathematics. Their curiosity and unrealistic expectations of using calculators decreased. They modified their attitudes and acquired a more accurate judgment and understanding of the functions of calculators in learning mathematics.

Prior research studies reported the differences in students' attitudes toward calculators by sex, grade, and ethnicity (Bitter & Hatfield, 1992; Huang & Waxman, 1993), examined the quality and quantity of calculator use (Suydam, 1984), and effects of hand-held calculators on mathematics achievement (Bitter & Hatfield, 1992; Hembree & Dessart, 1986). These studies contribute to the understanding and improvement of integrating calculators in a mathematics curriculum. The findings of this longitudinal study may add to these studies to provide a comprehensive assessment of the long-term impact of technology on student development in an affective domain. Future research may need to investigate whether there are differences in long-term effects by sex and ethnicity.

References

Bitter, G. G., & Hatfield, M.M. (1992). *Integration of the math explorer calculator into the mathematics curriculum: The calculator project report.* Tempe, AZ: Arizona State University, Technology Based Learning and Research.

Hambree, R., & Dessart, D. J. (1986). Effects of hand-held calculators in precollege mathematics education: A meta-analysis. *Journal for Research in Mathematics Education, 17,* 83-89.

Huang, S. L. (1993). Investigating middle school students' attitudes toward calculator use. In D. Carey, R. Carey, D.A. Willis, & J. Willis (Eds.), *Technology and Teacher Education Annual 1993* (pp.514-518). Charlottesville, VA: Association for the Advancement of Computing in Education.

Huang, S. L., & Waxman, H. C (1993). Classroom observations of middle school students' technology use. In D. Carey, R. Carey, D. A. Willis, & J. Willis (Eds.), *Technology and Teacher Education Annual 1993* (pp. 519-523). Charlottesville, VA: Association for the Advancement of Computing in Education.

National Council of Teachers of Mathematics. (1989). *Curriculum and evaluation standards for school mathematics.* Reston, VA: Author.

National Research Council. (1989). *Everybody counts: A report to the nation on the future of mathematics education.* Washington, DC: National Academy Press.

Suydam, M. N. (1984). Research on mathematics education reported in 1984. *Journal for Research in Mathematics Education, 16,* 243-315.

Table 1

Longitudinal Effects of calculator implementation on Students' Calculator Attitudes

	Post M	Post SD	Pre M	Pre SD	t
1. I feel smarter when I use a calculator.	2.54	1.00	2.68	1.01	-4.03*
2. Students should be allowed to use a calculator while taking math tests.	3.06	1.01	2.38	1.23	16.08*
3. The calculator will cause me to forget basic arithmetic facts.	0.98	0.98	1.27	1.11	-7.61*
4. Calculators make mathematics fun.	3.13	0.92	3.25	0.92	-3.65*
5. When I work with a calculator, I do not need to show my work on paper.	1.33	1.13	1.52	1.22	-4.15*
6. Math is easier if a calculator is used to solve problems.	3.30	0.85	3.45	0.82	-4.45*
7. I understand math better if I solve problems with paper and pencil.	1.66	1.01	2.06	1.00	-11.50*
8. I know how to use a calculator very well.	3.41	0.72	3.44	0.71	-0.98
9. It is important that everyone learn how to use calculators.	3.37	0.84	3.31	0.88	1.87
10. I do better in math when I use a calculator.	3.02	0.92	3.06	0.94	-1.21
11. I prefer working word problems with a calculator.	2.95	0.96	2.87	1.06	2.02
12. Using a calculator makes me try harder in math.	2.32	0.98	2.17	1.08	4.17*
13. Using a calculator to solve money problems is confusing.	0.62	0.85	1.02	1.07	-11.40*
14. Calculators should be used only to check work once the problem has been worked out on paper.	1.15	1.05	1.76	1.08	-17.02*
15. Calculators are useful for solving fraction problems.	3.51	0.86	2.67	1.19	20.58*
16. I feel calculators should be used on math homework.	3.34	0.83	2.84	1.09	13.71*
17. Using a calculator will cause me to forget how to do basic computation skills.	0.94	0.97	1.25	1.07	-8.38*
18. The calculator makes me a better problem solver.	2.62	0.98	2.57	1.08	1.28
19. If I continue to use a calculator, my estimation skill will decrease.	0.98	0.98	1.31	1.08	-8.45*
20. My parents do not like me to use a calculator for my math work.	0.89	1.08	1.54	1.20	-16.44*
21. Using a calculator helps me with my math work.	3.48	0.86	3.10	1.06	10.34*
22. In my math class, I know when I can and cannot use my calculator.	3.43	0.90	3.37	0.96	1.70
23. I have difficulty reading the calculator screen.	0.31	0.74	0.39	0.79	-2.60

* $p<.001$.

A Multimedia Lesson for Osmosis In Introductory Biology

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In 1990 we produced a multimedia program to illustrate the principles of osmosis. We chose osmosis because it is an important, fundamental biological process and many students have great difficulty understanding it correctly (see Friedler, Ruth, & Tamir, 1987). We chose a multimedia format because it can animate the random motion of molecules and provide motion picture sequences of osmotic events at the cellular and gross anatomical levels. The conceptual change theory of learning and understanding (Posner, et al., 1982) was used as the theoretical foundation for the program. According to that theory, information learned by a student is transformed to conform to their prior knowledge. If prior knowledge is flawed , i.e., contains misconceptions, new information is skewed to conform to the flawed knowledge; therefore, adjustments must be made within classroom lessons to account for students' misconceptions

Hardware and Software

The Osmosis Program is HyperCard based and requires an Apple Macintosh computer with at least a 13 inch monitor (a color monitor is not required) and 2500K free RAM (approximately 2000K for HyperCard and 500K for the Osmosis Program). Our specific set-up uses a Macintosh IIci, Pioneer LD 4200 laser disc player, Apple Video Drivers (contained within the Osmosis Program), a Sony projection system, and The Living Textbook (Life Science Series) laser disc from the Optical Data Corporation. The projection system can display either the laser disc images or the computer screen. While laser disc sequences are displayed, questions are posed to the students by the computer, thus requiring the instructor to toggle the monitor back and forth between the computer monitor and the laser disc sequences.

The Osmosis Program and Its Use

The Osmosis Program focuses on three important components of osmosis: 1) the random motion of molecules, 2) diffusion, and 3) osmosis itself, which are built on more specific concepts including concentration, concentration gradients, equilibrium, and differential membrane permeability. The goal of the program is to lead students to a more correct understanding of osmosis by getting them to examine what they *think* they know about the above concepts and to modify this knowledge when necessary.

To achieve this goal the program poses certain questions that cannot be answered correctly with a faulty understanding. To modify students' misunderstandings, the program poses a series of questions such as, "In which box is the concentration of oxygen higher?", accompanied by an appropriate graphic or animation. After students make a selection, the next screen of the program requires a written justification for their selection. This two-step procedure, of first making a multiple-choice selection and then justifying that selection, is used throughout the program. After completing the program, students should have a better understanding of osmosis and should be able to use their knowledge to describe, explain, and predict the outcome of osmotic events. Students can be "tested" on this ability at the end of the program when they view laser disc sequences of different biological events and choose which involve osmosis. This specific activity can also be used by the instructor at the beginning of the lesson to introduce the topic.

References

Friedler, Y., Ruth, A., & Tamir, P., "High school students' difficulties in understanding osmosis," Int. Journal of Science Education 1987, Vol. 9, pp. 541-551.

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A., "Accommodation of a scientific conception: toward a theory of conceptual change," Science Education, 1982, 66(2), pp. 211-227.

A Hypercard Program for Teaching about Carbon Allotropes

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The discovery of techniques for producing macroscopic quantities of fullerenes has focused a great deal of attention on this interesting class of compounds, propelling them into the forefront of chemical research. Unfortunately, however, few instructional materials exist to convey the excitement and novelty of all-carbon molecules to undergraduates.

We have developed a Hypercard program to teach students about the well-characterized forms of pure carbon: graphite, diamond, lonsdaleite ("hexagonal diamond"), and the fullerenes. The program is aimed at college sophomores with some background in organic chemistry, and teaches them about a major area of recent chemical research, something not often encountered in undergraduate courses.

For each substance, the student chooses from a menu containing the following topics: history, structure, preparation or natural occurrence, physical and biological properties, spectroscopy, chemistry, and applications. The program shows students the distinction between molecular and network forms of carbon, and is presented in a very visual format, emphasizing 3-dimensional structures. For example, in the Structure module, students can see the relationship between small-molecule building blocks and the different all-carbon solids. Benzene is seen as the repeating unit in graphite; chair and boat cyclohexane rings are highlighted in and seen alongside the structures of diamond and lonsdaleite; and the many different structural subunits of fullerenes are demonstrated.

The different modules of the program are interconnected at various points to help students understand the relationships between structure, spectroscopy, properties, reactivity, and applications. Branches in the program allow students to explore related topics such as small reactive carbon clusters. The student chooses his or her own path through the program.

The Effects of Computer-Assisted Instruction on African-American Postsecondary Students' Achievement and Attitudes Towards Mathematics

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Developmental education courses have often been instituted at postsecondary institutions in order to help students who lack some of the basic skills they need to be successful college students. The instruction in these courses, however, has typically been lecture-based, whole group instruction. Since didactic instruction was the prevalent instructional format that these lower-achieving students encountered while they were in secondary schools, it may be necessary to alter the postsecondary instructional learning environment so that these students have alternative opportunities to learn the required basic skills.

Instructional technology has been found to be an effective tool for redesigning the instructional learning environment and improving students' achievement and attitudes towards learning (Office of Technology Assessment, 1988). Although there have been a few studies that have examined the effects of technology on the attitudes and achievement of postsecondary students in developmental education courses (Lewis, Stockdill, & Turner, 1990; Love & Bickel, 1993; Wood & McElhinney, 1990), these studies have not exclusively focused on African-American students and they have not exclusively focused on mathematics. Consequently, the present study extends the research on computer assisted instruction by examining its effect on African American postsecondary students' attitudes and achievement in mathematics.

Method

The subjects in the present study were 231 freshmen students from a urban university located in a large major metropolitan area in the southwest. The subjects comprised nine classes of first semester remedial mathematics. The students were placed into remedial mathematics because they had skill deficiencies in algebra and geometry. Students were randomly assigned to nine sections of remedial mathematics, with about 25 students in each class. Four of the classes used computer-assisted instruction, and the remaining five classes were taught using the traditional lecture method.

The Algebra and Geometry sections of the Texas Academic Skills Program was administered at the beginning and end of the class. A modified version of Aikens-Dreger (1961) math attitude survey was also administered to all nine classes at the beginning and end of the 12 week course to measure students' attitude towards mathematics. This instrument consisted of 20 Likert-type items and the computed reliability for the instrument was .75.

The four classes using the computer used a software program called CRS-Integrated Learning System. CRS was developed by Computer System Research as an instructional management system for teaching mathematics. The program provides the following steps when teaching a concept: (a) introducing the concept, such as factoring, (b) provide rules and examples of factoring, and (c) a 20 problem posttest for the student to complete. CRS considers a student has mastered a topic if the student could correctly answer 80% of the practice problems. After mastery, the student would move to the next topic. If the student fails to master the objectives for the topic, the system will automatically return the student to the rules and examples for that topic. If the students fails the to master topic on the third try, the topic will be placed at the end of the topics to be covered. The teachers in these classrooms were used to monitor students progress.

CRS was also used to teach the geometry sections for the two computer-assisted classes. CRS was selected for geometry instruction over several other packages due to its ability to graphically represent problems. Similar to the algebra instruction, the geometry section of CRS begins by introducing the concept, followed by rules and examples, and concluding with a follow-up test. The five remaining classes were taught using lecture mode.

Each of the nine classes received 6 weeks of instruction in algebra and 6 weeks in geometry. All nine classes consisted of 50 minute periods that were taught three times a week.

Results and Discussion

Analysis of Covariance (ANCOVA) was used to examine the effectiveness of the two methods of instruction on students': (a) geometry skills, (b) algebra skills, and (c) attitudes toward mathematics. Table 1 reports the pretest means, posttest means, and adjusted means for the the three outcomes. The results indicate that there was a significant differences ($p < .05$) between the two groups on geometry skills and students' attitude toward mathematics. For both outcomes, students in the computer-assisted group scored significantly higher than the control group, after controlling for pretest scores. There were no significant differences between the two groups on the algebra skills test.

The results of the present study indicate that computer-assisted instruction can be effective in teaching developmental mathematics courses. These findings also suggest that students taught using computer-assisted instruction do better in geometry, but the effects of this program are not necessarily effective in other content areas of mathematics such as algebra. Future studies need to consider other appropriate content areas where computers could be effectively used.

Another important factor considered in this study was how computer-assisted instruction affects students' attitude towards mathematics. The results indicate that students have more positive attitudes towards mathematics when computers are used. Future studies should examine whether or not there are ethnic- and/or sex-related differences that might influence mathematics achievement and attitudes when computers are used. Moreover, studies need to examine if these findings are consistent across across other sites or for other ethnic groups. In summary, the findings from the present study are promising in that it appears that computer-assisted instruction may be beneficial for those African-American postsecondary students who have not done well in mathematics using traditional instructional methods.

References

Aiken, L. R., & Dreger, R. M. (1961). The effect of attitudes on performance in mathematics. *Journal of Educational Psychology, 52*, 19-24.

Office of Technology Assessment (1988). *Power on: New tools for teaching and learning*. Washington, DC: U. S. Government Printing Office.

Lewis, D. R., Stockdill, S. J., & Turner, T. C. (1990). Cost-effectiveness of microcomputers in adult basic reading. *Adult Literacy and Basic Education, 14*, 136-149.

Lowe, N., & Bickel, R. (1993). Computer-assisted instruction in Appalachia's postsecondary schools. *Journal of Educational Research, 87*, 46-52.

Wood, G. S., & McElhinney, J. H. (1990). Evaluating the performance of a computer-based literacy instructional program. *Adult Literacy and Basic Education, 14*, 18-27.

Table 1

	Computer			Lecture			
	Pre M (SD)	Post M (SD)	Adjusted M (SE)	Pre M (SD)	Post M (SD)	Adjusted M (SE)	F-value
Geometry	14.01 (3.38)	24.39 (2.76)	26.18 (0.78)	14.49 (3.67)	20.74 (3.18)	18.77 (0.82)	6.00**
Algebra	14.01 (3.38)	20.82 (3.04)	21.81 (0.81)	14.47 (3.67)	23.93 (3.05)	22.91 (0.86)	0.40
Attitudes	53.88 (12.99)	70.27 (13.86)	77.11 (3.99)	55.72 (14.15)	58.94 (14.62)	51.59 (4.20)	3.82*

* p<.05; ** p<.01

Educational Software for the Visualization of Space Plasma Processes

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Physical processes in space plasmas occur over hundreds to millions of kilometers and are not scalable to a laboratory setting. Thus it is difficult without the aid of computers to provide students in space physics "practical" training in the laboratory. In order to address this problem, the UCLA Space Physics Group has begun to develop a series of software modules that enable students to perform laboratory type experiments on a Unix workstation in an X-Window environment. The software is designed around the principle that students can learn more by doing rather by reading or listening. It provides a laboratory-like environment in which the student can control, observe and measure complex behavior. The interactive graphics environment allows the student to compare theoretical and model results with "observations" obtained using these modules, to visualize the results of his or her experimentation, and to try different parameters as desired. They reinforce the classroom instruction, and develop physical intuition.

The Space Physics Education Software was developed to run on Sun and HP workstations using C, X-Windows and MOTIF/Openlook. The Space Physics Education Software can be run "remotely" at our site at UCLA and displayed on any suitable local machine's display. The only requirement is that the local machine run X-windows. This includes Macintoshes, which run the Mac-X program. Local copies of the Space Physics Education Software can be made easily as well. Only two files need revision to create an executable on a new system. These two files are the Makefile and the X window resource files.

The Learning Modules

Six modules are presently available. While designed as an adjunct to a lecture course in space physics, some of these modules would be useful in teaching more basic plasma physics concepts.The Magnetospheres module is designed to introduce students to some of the elementary properties of planetary magnetic fields. It allows measurements of the magnetic field in a variety of planetary magnetospheres. The Particle Motion module is designed to demonstrate the behavior of single charged particles in a variety of magnetic field configurations. It allows the student to follow the motion of ions and electrons of varying energy in magnetic and electric fields of varying geometry. The Cold Plasma Waves module is designed to introduce students to electromagnetic waves in a cold plasma. It allows the student to explore the cold plasma dispersion relation for different plasma conditions. The Solar Wind module is designed to communicate some concepts related to solar wind and interplanetary magnetic field behavior. It illustrates the radial variation of the solar wind and how the current sheet affects the structure of the interplanetary magnetic field. The MHD/Collisionless Shock module is designed to illustrate how collisionless shocks affect plasma properties. It allows the student to calculate how the solar wind plasma and magnetic field vary across a collisionless shock. Finally the Currents module enables the student to determine the magnetic field at the surface of the Earth due to an infinite line current in the ionosphere above. These modules will continue to be enhanced and new modules will be added in the future.

From our experience at UCLA, interactive menu-driven graphics software is a good way to introduce students to the physical processes occurring in space plasmas. We have developed modules for magnetospheres, particle motion, cold plasma, solar wind, collisionless shocks, and currents. These modules need extension and we need more modules to provide a more complete curriculum. They are now being used in both upper division and graduate classes at UCLA and have recently been introduced at UCSD. The modules have been best received in computer laboratory situations where the instructor is available to answer questions. Remote dial-in usage has been less successful due principally to interfacing problems with x window emulators. Graduate students prefer remote dial-in capability because it allows them freedom to arrange their schedules but such freedom comes at the price of decreased interaction with the instructor.

A Reasoner's Workbench for Improving Scientific Thinking: Assessing *Convince Me*

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The *Theory of Explanatory Coherence* (TEC), and its implementation as a connectionist computer model (ECHO; e.g., see Ranney & Thagard, 1988), offer an account of how people evaluate hypotheses, evidence, and other propositions about various situations. We have found that ECHO usefully predicts subjects' reasoning (e.g., Schank & Ranney, 1991, 1992). With insights arising from these experiments, we have developed *Convince Me*—a TEC-based "reasoner's workbench" program—and an associated reasoning curriculum. These are for helping adolescents and young adults structure, restructure, and assess their knowledge about often-controversial situations (Schank & Ranney, 1993; Ranney, Schank, Mosmann & Montoya, 1993). Students may observe *Convince Me* as it models scientific debates, but they primarily use it to input and evaluate their own arguments: it asks students to (1) input their own situational beliefs, (2) interactively categorize them as hypotheses or evidence, (3) indicate which beliefs explain, contradict, or compete with which others, and (4) rate their beliefs' plausibilities. Each student's argument is then simulated, thus predicting which beliefs "should" be accepted or rejected. After contrasting their ratings with the simulation's predictions, students may (a) alter their argument's structure, or (b) tailor ECHO to better suit their individual reasoning styles. Thus, *Convince Me* offers both a robust interface for explicating and revising arguments *and* a "reasoning engine" for coherence-based assessments of one's beliefs.

Recent results show that training with *Convince Me* generally made ten undergraduate "novices" behave more like ten experts (who study reasoning professionally). We gathered subjects' ratings on how much given propositions seemed (1) evidential, (2) hypothetical, and (3) believable. After using the *Convince Me* software and curriculum for four or five hours, novices more strongly (a) discriminated evidence from hypothesis, (b) doubted statements that they rated as more hypothetical, and (c) associated believability with evidence-likeness. For example, in a textual context, *experts'* ratings of a proposition's hypothesis-likeness correlated with its evidence-likeness at -.65, compared to -.3 with no context; after training, novices' correlations mirrored these. Experts' goodness ratings of novices' definitions of several terms (hypothesis, evidence, theory, fact, etc.) revealed that novices' definitions also significantly improved after training (from an initial mean of 16.5 to one of 25.7, out of 33 possible points). We are currently assessing *Convince Me*'s effectiveness by contrasting 20 students' performance under two conditions—in which they carry out exercises (1) using *Convince Me*, or (2) on paper.

We find that the distinguishing characteristics of data and theory are still vague—even for experts (whose inter-rater reliabilities for evidence- and hypothesis-likeness are fairly low). Still, our reasoner's workbench lends sophistication to novices' discriminative criteria and definitions, making their epistemic categorizations seem more expert-like. We continue to analyze these (and related) issues regarding the system's effectiveness, as well as more general issues about scientific reasoning.

References

Ranney, M. (in press). Explorations in explanatory coherence. To appear in E. Bar-On, B. Eylon, and Z. Schertz (Eds.) *Designing intelligent learning environments: From cognitive analysis to computer implementation*. Norwood, NJ: Ablex.

Ranney, M., Schank, P., Mosmann, A., & Montoya, G. (1993). Dynamic explanatory coherence with competing beliefs: Locally coherent reasoning and a proposed treatment. In T. Chan (Ed.), *Proceedings of the International Conference on Computers in Education: Applications of Intelligent Computer Technologies* (pp. 101-106).

Ranney, M. & Thagard, P. (1988). Explanatory coherence and belief revision in naive physics. *Proceedings of the Tenth Annual Conference of the Cognitive Science Society*, 426-432. Hillsdale, NJ: Erlbaum.

Schank, P., & Ranney, M. (1991). An empirical investigation of the psychological fidelity of ECHO: Modeling an experimental study of explanatory coherence. *Proceedings of the Thirteenth Annual Conference of the Cognitive Science Society*, 892-897. Hillsdale, NJ: Erlbaum.

Schank, P., & Ranney, M. (1992). Assessing explanatory coherence: A new method for integrating verbal data with models of on-line belief revision. *Proceedings of the Fourteenth Annual Conference of the Cognitive Science Society*, 599-604. Hillsdale, NJ: Erlbaum.

Schank, P. & Ranney, M. (1993). Can reasoning be taught? *Educator*, 7 (1), 16-21. [Special issue on Cognitive Science and Education].

Implementing the "Wheels of Learning, Teaching and Assessment (WLT & A) Model" in Science Education

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Introduction

Learning has traditionally been sandwiched between teaching and assessment. The "Wheels of Learning, Teaching and Assessment (WLT & A) Model" breaks the "sandwich barrier" (see Figure 1a) to learning by turning the sandwich inside out as shown in Figure 1b.

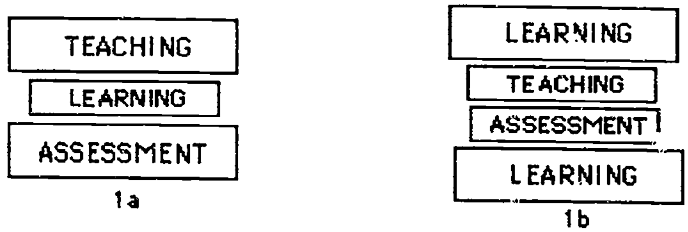

Figure 1. Breaking the "Sandwich Barrier" to Learning

The WLT & A Model

Wheels of Learning

The WLT & A Model recognizes the fact that different people prefer to learn in different ways. By providing opportunities for students to learn in ways which they prefer to learn, the WLT & A Model ensures that all students assume responsibility for their own learning. It also ensures that all students maximize their learning potential. In this model each student creates her or his own 'Wheel of Learning.'

Wheels of Teaching

Just as students prefer to learn in different ways, they also prefer to learn from different sources. The classroom teacher is one of the many sources students learn from. The classroom teacher is always a part of the 'Wheel of Teaching' which each student creates for herself or himself.

Wheels of Assessment

In this model, students may be assessed in different ways. Students create their own individual 'Wheels of Assessment,' to demonstrate that they have indeed learned what they were supposed to learn. Students learn more as they think about the different ways in which they can demonstrate that they have learned.

Role of the Teacher in the WLT & A Model

The classroom teacher plays a pivotal role in the WLT & A Model. It is the teacher who sets the 'Wheels of Learning, Teaching, and Assessment' in motion. It is also the teacher who encourages and motivates students to sustain the motion of the wheels of learning, teaching, and assessment.

The Influence of Calculator Use on Limited-English Proficient Hispanic Students' Mathematics Problem-Solving Achievement

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One of the greatest challenges facing mathematics educators is providing effective instructional interventions for Hispanic limited-English proficient (LEP) students who have been found to have significantly lower mathematics and problem-solving achievement than other minority and majority students (Anrig & LaPointe, 1989; Carson, Huelskamp, & Woodall, 1993). One instructional approach that has been found to be effective for improving students' mathematics is integrating calculators into the mathematics curriculum (Bitter & Hatfield, 1992, 1993; Hembree & Dessart, 1986, 1992; Mathematics Science Education Board, 1990, 1991; National Research Council, 1989). There have been very few research studies, however, that have specifically examined the effects of calculator use on higher-level student outcomes like problem-solving achievement (Szetela & Super, 1987). Furthermore, there have not been any studies that have specifically investigated the effects of calculator use in middle schools on Hispanic limited-English proficient (LEP) students' problem-solving achievement in mathematics.

The objective of the present study is to investigate the influence of calculators on Hispanic LEP middle school students' problem-solving achievement in mathematics. More specifically, this study examines whether or not the degree of implementation of calculators in mathematics classrooms affects the problem-solving achievement of Hispanic LEP students.

Method

The subjects in the present study were 199 Hispanic middle school (i.e., grades 6, 7, & 8) students who were all categorized by the school district as limited-English proficient (LEP) based on test score results from the Language Assessment Scales test. The majority of the students in the present study were from lower- to middle-class families. Their overall achievement level in mathematics was slightly lower than the national average. The gender distribution among these students was: 46.6% female and 53.4% male.

In this multi-ethnic school district which was located within the vicinity of a major metropolitan city in the South Central region of the United States, all LEP students are taught mathematics in regular classrooms. The school district was selected to be included in the present study because it had recently been awarded a grant from the Department of Education involving the integration of calculators in mathematics instruction. As a result of the grant, all middle school students in the school district were issued a calculator that they could use for both school and home along with his or her mathematics text. In addition, all middle school mathematics teachers in this district received at least 12 hours of inservice training to help incorporate calculators into their instruction. Calculator curriculum activities that had been developed by a writing team during the first year of this project were made available to each mathematics teacher in the district. All teachers in the district were encouraged to utilize these activities and any others found to aid mathematics with calculators.

Students' problem-solving achievement was measured near the end of the school year using the Four-Step Problem Solving Test (Hofmann, 1986). The Four-Step test consists of 10 nonroutine mathematics problems, each with four related questions: (a) reading to understand the problem, (b) selecting a strategy, (c) solving the problem, and (d) reviewing and extending the problem. It is a multiple-choice, paper-and-pencil test designed to measure problem-solving mathematics skills of middle school students. The range for the total test is 0 to 40.

Near the end of the school year, a student survey was administered to all students to assess their perceptions of the amount of time they used calculators during their mathematics class. Analysis of variance was used to examine if there were differential effects of the amount of time students reported using calculators on students' postproblem-solving achievement. This posttest only design was used because students were randomly assigned to their mathematics classes. It should also be noted that there were no significant differences found by grade level or the interaction of grade level and amount of time students reported using calculators.

Results and Discussion

The survey results revealed that approximately 31% of the students reported that they used calculators in their mathematics class "everyday." About 30% responded that they used calculators about "three or four times a week," and about 39% indicated that they used calculators "one or two times a week." The analysis of variance results indicate that there were statistically significant differences on students' postproblem-solving achievement by students' responses regarding the amount of time they used calculators in their mathematics class. Students who reported using calculators "every day" in their mathematics class and students who reported using calculators "three or four times a week," scored significantly higher ($F\ (2,196) = 6.06$, $p < .01$) than students who reported using calculators "once or twice a week." These findings are both statistically significant and practically significant. The adjusted posttest means among the three groups or categories of calculator use are nearly three points different. That is, students in the "everyday" category scored about one point higher ($Adj\ M = 15.58$) than students in the "three to four times a week" category ($Adj\ M = 14.59$) and almost three points higher than students in the "one to two times a week" category ($Adj\ M = 12.92$).

The findings from the present study suggest that the more often Hispanic LEP students reported using calculators, the higher their problem-solving achievement. More studies, however, are needed to replicate the present study as well as conduct new experimental and longitudinal studies that examine the influence of calculators on Hispanic LEP students' mathematics achievement. The descriptive findings related to students' calculator use in the present study are very similar to the findings obtained by Huang and Waxman (1993), who used systematic classroom observations to assess the amount of calculator use in these same classrooms. More systematic classroom observation studies, however, need to be conducted to concurrently to examine the validity of students' perceptions of technology use as well as the effects of classroom instruction on students' problem-solving achievement. Finally, more qualitative studies need to be conducted to explore *why* calculator instruction appears to benefit Hispanic LEP students

References

Anrig, G. R., & LaPointe, A. E. (1989). What we know about what students don't know. *Educational Leadership, 47*(3), 4-9.

Bitter, G. G., & Hatfield, M. M. (1992). Implementing calculators in a middle school mathematics program. In J. T. Fey & C. R. Hirsch (Eds.), *Calculators in mathematics education* (pp. 200-207). Reston, VA: National Council of Teachers of Mathematics.

Bitter, G. G., & Hatfield, M. M. (1993). Integration of the math explorer calculator into the mathematics curriculum: The calculator project report. *Journal of Computers in Mathematics and Science Teaching, 12*(1) 59-81.

Carson, C. C., Huelskamp, R. M., & Woodall, T. D. (1993). Perspectives on education in America: An annotated briefing. *Journal of Educational Research, 86*, 259-309.

Hembree, R., & Dessart, D. (1986). Effects of hand-held calculators in precollege mathematics education: a meta-analysis. Journal for Research in Mathematics Education, 17, 83-99.

Hembree, R., & Dessart, D. J. (1992). Research on calculators in mathematics education. In J. T. Fey & C. R. Hirsch (Eds.), *Calculators in mathematics education* (pp. 23-32). Reston, VA: National Council of Teachers of Mathematics.

Hofmann, P. S. (1986). *Construction and validation of a testing instrument to measure problem-solving skills of students.* Unpublished doctoral dissertation. Philadelphia: Temple University.

Huang, S. L., & Waxman, H. C. (1993). Classroom observations of middle school students' technology use in mathematics. In D. Carey, R. Carey, D. A. Willis, & J. Willis (Eds.), *Technology and teacher education annual 1993* (pp. 519-523). Charlottesville, VA: Association for the Advancement of Computing in Education.

Mathematics Sciences Education Board (1990). *Reshaping school mathematics: A philosophy and framework for curriculum.* Washington, DC: National Academy Press.

Mathematics Sciences Education Board (1991). *Counting on you: Actions supporting mathematics teaching standards.* Washington, DC: National Academy Press.

National Research Council (1989). *Everybody counts: A report to the nation on the future of mathematics education.* Washington, DC: National Academy Press.

Szetela, W., & Super, D. (1987). Calculators and instruction in problem solving in grade 7. *Journal for Research in Mathematics Education, 18*, 215-229.

Localization of Information in Diagrams: Low Benefit Cases for Science Learners

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Despite a well-established interest of science educators in the role of diagrammatic representations in learning (diSessa, Hammer, Sherin, & Kolpakowski, 1991; Hall, 1990; Hildebrand, 1990; Wilkin, 1992; 1993; 1994), most technology-based educational tools tend to incorporate diagrams intuitively rather than on the basis of well-articulated guidelines of design. What the Mathematics and Science Education community needs is a well worked-out theory of the role of diagrams in the learning process. This theory should lay out the general cognitive properties played by diagrammatic representations in the learning process and propose guidelines so that educational software can be designed appropriately.

The present paper is a contribution to these issues. It focuses on the property of localization in diagrams. Larkin and Simon (1987) have proposed that diagrammatic representations are useful because they index information by location in a plane. As a result, a single location provides much of the information needed to make an inference. This is a more powerful feature than the linear organization of a sentence. This analysis, however, was carried out in the context of problem solving rather than learning. We know little about the effect of localization on learning and its implications for the design of educational software. The present paper studies this issue by analysing subjects' verbal and pictorial explanations as they study a physics text about motion in a curved path.

Ten subjects with naive conceptions about motion in a curved path were asked to think aloud while studying a chapter and a worked-out example on this topic, took three tests (explanation, isomorphic, and transfer), and were divided into a Low Benefits (LB) and a High Benefit (HB) learners' group on the basis of a post-hoc median split on postest measures. Analysis of their verbal protocols and drawings shows that the LB learners used diagrammatic representations extensively, relying on their features to make sense of the text, whereas the HB learners processed the text conceptually. It was found that, contrary to Larkin and Simon (1987)'s emphasis on the benefits of adjacency of information in a diagram, spatial localization of diagrammatic features played an inhibitory role on the learning process because access to adjacent features of a diagram led to the propagation of inaccurate comprehension.

This preliminary result shows that learners in the process of acquiring new conceptual knowledge are not necessarily helped by local diagrammatic features because they can use them indiscriminately. It follows that educational software should be designed to help learners discriminate between local features by trying to reinforce the distinctiveness of such features. More investigation is needed to find in what way.

References

diSessa, A., Hammer, D., Sherin, B., & Kolpakowski, T. (1991). Inventing Graphing: MetaRepresentational Expertise in Children. *Journal of Mathematical Behavior, 10*, 117-160.

Hall, R.P. (1990). *Making Mathematics on Paper: Constructing Representations of Stories About Related Linear Functions*. Ph.D. dissertation, University of California, Irvine.

Hildebrand, A. C. (1990). *Pictorial Representations and Understanding Genetics: an Expert/Novice Study of Meiosis Knowledge*. Ph.D. dissertation, University of California, Berkeley.

Larkin, J. H., & Simon, H.A. (1987). Why a Diagram is (Sometimes) Worth Ten Thousand Words. *Cognitive Science,11*, 65-99.

Wilkin, B. (1994). *The Self-Explanation Effect With Self-Generated Diagrams*. Technical Report CSM 9, University of California, Berkeley.

Wilkin, B. (1993). *When One does not Learn From Explanations.* Paper presented at the 25th Berkeley-Stanford Symposium in Cognitive Psychology.

Wilkin, B. (1992). Cognitive Processing of an Illustrated Text About Motion in a Curved Path. *International Journal of Psychology, 27*, 3-4, 107-117.

Author Index