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AUTHOR	Kellogg, Ted; Latson, Jon
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ABSTRACT

There are two major concerns about the teaching of high school biology. One is the degree to which students memorize laws, facts, and principles, and the second involves the role of the classroom teacher. These aspects result in a discrepancy between the theory and practice of science education. The purpose of this report is to provide: (1) a recapitulation of the targets causing the difficulty, the rationale, and the research questions; (2) a chronology of 18 months of work; (3) descriptions of the instructional material, teacher training, software, and experiments performed; (4) research findings; and (5) provisional conclusions and relevant issues concerning the research. Teachers involved in the study stated that they would use the technique again. Pilot teachers admitted feeling more comfortable using the materials in teaching the second class than their initial class. Most teachers found that the higher level of thinking required and the use of the scientific method made the materials more appealing. About one in eight of the teachers preferred alternate materials or teaching strategies to this method. The appendices include suggested revisions of software, tally sheets, homework assignments, teacher pre/post questionnaires, a student post questionnaire, and student pre/post tests. A reference list is also cited. (RT)

TEACHING SCIENTIFIC METHODOLOGY THROUGH MICROCOMPUTER SIMULATIONS IN GENETICS

Final Project Report

July 1986

Educational Technology Center
Harvard Graduate School of Education
337 Gutman Library Appian Way Cambridge MA02138

Teaching Scientific Methodology through Microcomputer Simulations in Genetics

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prepared by Ted Kellogg and Jon Latson

Rhode Island/Brown Technology

<u>Group Members</u>

Maurice Blais
Paula Evans
Bennie Fleming
Ted Kellogg
Jon Latson
Edward Pascarella
M. Boris Rotman

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RHODE ISLAND / BROWN TECHNOLOGY CONSORTIUM

TECHNICAL REPORT

The purpose of this report is to provide: 1) a recapitulation of our targets of difficulty, our rationale, and our research questions; 2) a chronology of our eighteen months of work; 3) descriptions of the software and experiments conducted; 4) our research findings, based on observations of eight teachers using the experimental unit; 5) provisional conclusions and relevant issues concerning our research.

INTRODUCTION

Approximately one year ago, the Rhode Island / Brown Technology Consortium began its study of twin targets of difficulty in high school biology: 1) engaging students actively in the scientific method and 2) changing the role of the teacher from lecturer and conclusion drawer to initiator and facilitator. These targets are a response to two major concerns about the teaching of high school biology.

One concern is the degree to which students do little more than memorize facts, laws, and principles. Textbooks and lectures are *descriptive* in their approach rather than *experimental*. In theory, class laboratory experiments are intended to provide opportunities to explore problems, manipulate variables, and individually draw meaningful conclusions. In practice, however, the experiments become simple demonstrations designed only to present facts already known to the student. Furthermore, laboratory work is frequently unsuccessful because of time constraints or student confusion and error. Students often do not go through the complete process intended in the experiment, spend little time analyzing what they are doing, and are afraid to share hypotheses. In many cases, insecure about their own results, students want the final, "correct" answer.

Another concern involves the role of the teacher in the science classroom. All too often he/she is the primary focus of the educational activity. Using the declarative tools of lecture and textbook, the teacher becomes the "expert" intent upon the subject matter, presenting, explaining, and exemplifying those scientific concepts and principles that were originally derived by exploration, experimentation, and speculation.

Our purpose is to use a single computer with a large screen and video projector as the focus of the class, running software engaging students in the process of examining phenomena related to genetics. The computer presents a certain situation; the class selects experiments to test the situation, gathers data, and discusses the ongoing investigation to determine what to do next.

Such computer-based materials are not unlike the "Invitations to Enquiry" (Klinkmann, 1970) of the *Biological Sciences Curriculum Study* (BSCS). These enquiries had been proposed by Schwab (1960), to enhance science teaching. He foresaw two stages of activities which would lead to an enquiry classroom, one in which students explored the process of enquiry (today this might be called metacognition of scientific processes). First, students would encounter the materials, data, and analysis by which scientific conclusions are reached. Second, students would engage in discussion of the scientific endeavor. The discussion would include what the problem was, what was known, what data were needed, what the limits were of what was learned, and what new questions existed.

While we share the goals of the "Invitations," we have used the features of the computer to extend the sense of doing science in the classroom. The computer activity is designed to allow the teacher to assume the role of the facilitator and to decrease his/her role of information authority.

Our intention has been to address the following research questions:

1. Will science teachers be receptive to a new pedagogical style in which the teaching pace is partially set by a computer?

2. Will receptive teachers perceive their role in the classroom differently, and will they be able to modify their teaching style?

3. Will computer-guided activities in front of a class be an effective focus of attention and address the targets of difficulty?

4. Will students engage in inductive reasoning and establish logical connections while testing hypotheses?

As happens in research, we have shaped our tools and our tools have shaped us. A formative part of our research design has evolved from our first efforts to develop a set of lessons based on our initial objectives. Initially we had in mind a two-week sequence of lessons in which a class of students would conduct simulated experiments as a group on a computer and act out the steps of the scientific process with particular emphasis on hypothesis testing. The teacher was to assume the role of discussion stimulator, consultant, and clarifier when necessary of the student activity. In this way students would practice the desired reasoning process rather than simply witness it, and science education would move from the descriptive to the experimental. Having now piloted the lessons in fourteen classes involving eight (8) teachers and collected substantial information still to be analyzed, we are preparing to focus our research questions, narrow the scope of our examination and identify relevant areas in which to conduct further research.

CHRONOLOGY

The Rhode Island / Brown Technology Consortium began in early 1985 with meetings held by the Brown University Education Department bringing together members of public and private schools and the Rhode Island Department of Education. A collaborative effort among secondary educators and Brown professors and educational researchers to undertake a project studying the use of technology in science education at the secondary level was discussed. The topic of hypothesis testing in biology emerged in our early discussions as an appropriate and significant target of difficulty. Mendelian genetics was agreed upon as an area in biology where this topic of difficulty was particularly manifest; teachers usually take the approach of presenting the laws and the students learn them as abstract mathematical relationships rather than conclusions based on experimentation and observation. If high school students are to learn how to be scientists studying real phenomena, clearly a more experimentally based approach should be implemented.

It was felt that the use of the computer as a pedagogical tool would need to be a tool for the teacher in conducting a class rather than a CAI or tutorial substitute for a whole class activity. Therefore, the group began brainstorming about scenarios in which the computer "conducted" the class, and the teacher became an assistant to the students engaging the class in examining hypotheses, gathering data, and drawing conclusions. Such an approach would not be easy for teachers who had established a style based of teacher-centered activities, so the target of difficulty was expanded to include the challenge of modifying teacher behavior from the role of lecturer to that of facilitator.

Commercial software was examined but found to be suited more as a supplement to a lesson in genetics and to be used by individuals and small groups rather than as a computer activity to guide an entire class. To conduct our intended experiment, we decided to develop our own software.

Most of the summer of 1985 was spent in revising the formal proposal and in writing the software to be tested during the following academic year. As a research team, we were concerned not only with developing an instructional unit that would work in an actual class, but also with building in the analytical tools necessary to extract meaningful data from the class experience. Our research questions posed challenges to developing the right devices to provide answers. We began outlining pre-test / post test designs, student and teacher questionnaires, and developing approaches to evaluating video tapes we planned to make of the experimental classes.

In November, 1985, just days before our first pilot, the software was demonstrated on two occasions to members of ETC (at an ETC open house and subsequently at a meeting with the ETC executive staff). One outcome of these presentations was our awareness of the difficulty in communicating the intended use of the software. By presenting the software outside the context of a model class, misconceptions about its purpose and completeness occurred. On the one hand the software seemed rigid and on the other hand incomplete. Before educators outside the research group would be able to use the unit, a carefully devised teacher training workshop would need to be presented to stress the crucial pedagogical techniques involved in the teacher becoming a facilitator.

The first pilot was conducted in late November by one research group member. We were anxious about how easy the unit would actually be to conduct in a class where conventional student and teacher behaviors had already been established. Further, we were looking for shortcomings in the software as well as the instructional and evaluation materials. The outcome indicated that, with some fine-tuning, the experimental unit was viable. Changes and additions were made, and a second pilot using another member of the research team was conducted in early February.

In late February, 1986, the project was again presented, this time to a group of high school biology teachers. Clips of the video tapes made during the pilots were shown first and a discussion of the facilitator approach to conducting a class was held before the software was shown. Teachers asked many insightful questions and expressed much enthusiasm for using such a unit.

During the spring of 1986, we took the results of the two pilots and again revised the instructional unit. The prompting in the programs was made more direct and specific and additional controls were added to keep the teacher on track with the software. The teacher training workshop was mapped out in light of likely trouble areas in the unit our pilot teachers encountered. Techniques for analyzing the video tapes were nailed down. On May 1, 1986, the training workshop was held for the six teachers who would be conducting the experimental classes, and May 5 - 15 the classes were carried out in two Providence area schools.

During June, 1986, our research group met several times to review the observations and video tapes of the experimental classes and to meet with the teachers who had conducted those classes. We also found ourselves at this point able to reflect upon the research questions we had asked a year before and to consider our future direction.

DESCRIPTION OF SOFTWARE

Much of the progress of our research group during the first months was measured in terms the development of the software. Since the computer was to be the focus of the class, the software description also summarizes the content of the classes. The results of the first pilot gave us many ideas for software revision, and many changes and additions to the content were made before the second pilot.

The software used in the second pilot and the experimental classes consisted of a greeting program which served as a main menu, and four programs which were to be administered in order: "Filter Paper Experiment," Taster Marriages," "The Islands," and "Two Jars." All programs are based on the genetic distinction between people who can taste Phenylthiourea and those who do not taste that chemical.

The software was written in BASIC for any Apple][computer with 64K RAM. All frames are written on the graphics pages to allow for mixing graphics and text and for using various text fonts. Pictures were drawn using a Koala Pad (Koala Technologies); animation and shapes were done using The Graphics Magician (Penguin Software); text fonts came from The Graphics Magician and Apple Mechanic (Beagle Bros.).

The greeting program opens with a graphic of a stage, a musical fanfare, and the opening credits. The credits are replaced with a menu of the four programs.

"Filter Paper Experiment" opens with a sequence of directions to the teacher to administer a red piece of untreated filter paper to each student to taste (red papers are plain) and then a blue piece of chemically treated filter paper. The students are asked to record a T if they taste a difference between the red and blue papers or an NT if no difference is perceived. The teacher enters the number of Tasters and Non-Tasters and the percents of the total number of students are displayed. Students enter this information on their Data Sheets and consider the question: "Are these data typical for other classes?".

The next screen displays data of other classes (each of 20 students), and the first hypothesis is presented: "The percentage of T and NT is the same for any group." Students are asked to consider the question that will appear after every hypothesis: "Are the data consistent with the hypothesis?". Since the data show a typical spread of percents for groups of 20, students will answer No or be asked to think again.

A second hypothesis is presented still showing the same data and the question: "There are more Tasters than Non-Tasters for any group." The answer here will be a Yes. Students are prompted to consider what other tests might be required to accept hypothesis II and are provided with a menu to see: 1) other groups of 20, 2) smaller groups, 3) larger populations. Hypothesis II will be disconfirmed after collecting sufficient data about small groups. After several selections from the menu, students are allowed to consider a third hypothesis: "The percentage of T and NT is the same for all large groups." This hypothesis is confirmed after looking at all the data about large groups.

"Taster Mariages" opens with the hypothesis: "Tasting ability is inherited." Students are provided with five males and five females, each of whom is labeled Taster or Non-Taster. Students may "marry" any pair and observe the Taster/Non-Taster breakdown of their progeny (20 children are observed after each marriage). Students continue to gather data until they feel they have tested the opening hypothesis sufficiently. Then they must respond Yes or No to three statements: 1) Two NT parents have only NT children, 2) Two T parents have only T children, 3) One T parent and one NT parent have only T children. Because Tasters may carry and NT gene, statements #2 and #3 are correctly answered "No." After responding to the statements, students may return to do more experimenting to determine that phenomenon.

"The Islands" opens with a picture of three tropical islands labeled

Taster, Non-Taster, and Meeting. A story is told about how all the inhabitants of Taster island have always been Tasters and all inhabitants of Non-Taster island have been Non-Tasters. One day natives of each island go to Meeting island where each marries someone from the other island. Their progeny, the first Meeting island natives, are all Tasters. The three statements from "Taster Marriages" are posed again, and, in light of the data concerning the progeny on Meeting island so far, students are asked to respond to each statement. The Meeting island natives grow up and marry one another, and data is collected on their children: out of 4000 children of Meeting island natives, 3000 are Tasters and 1000 are Non-Tasters. Students are again asked to consider the three statements, in light of the most recent data.

The next frame of the program invites students to "marry" any combination of inhabitants on Meeting island for whom they do not already have data about progeny. When students feel they have gathered sufficient information, they are asked to consider three hypotheses and fit every possible datum collected from the three islands to confirm or disconfirm the hypothesis. Hypothesis I: Non-Tasters pass a factor to all their progeny which prohibits tasting. Hypothesis II: Tasters pass a factor to all progeny. Non-Tasters lack this factor. Hypothesis III: Each offspring receives a factor from each parent; offspring with one taste factor are tasters. Only Hypothesis III satisfies the entire set of data.

"Two Jars" opens with a recapitulation of Hypothesis III and discusses its ramifications by presenting the model of each parent as a jar containing balls that are labeled T or N. Beginning with T's and N's in each jar, students are asked to predict the outcome of each of the four possible combinations of factors (balls) from the mother and father.

Next, students are offered a menu of selections in which they may observe data concerning single or multiple offspring for parents whose type the students determine (either all N's, all T's, or N's and T's). A third choice is to guess the mother's type by selecting the father's type and observing a sufficient number of offspring. In the course of guessing the mother, students are asked to consider the effectiveness of each possible choice for the father's type in determining the mother's type.

The current software is considered unfinished. Following the experimental classes the project staff suggested a number of revisions which are included in Appendix A.

INSTRUCTIONAL MATERIAL DESCRIPTION

Beyond the software, instructional materials included a supply of red (untreated) and blue (treated) filter paper for the first day's experiment and Data Sheets, forms created to correspond to the data presentation on the screen to facilitate the transcription by each student of the results of various simulated experiments during the unit (Appendix B). These tally sheets allowed students to refer to previous information without calling up the screen display again and to keep a record of the results for the homework assignments and the following day's activity. Homework assignments were given after each of the first three lessons (Appendix C).

TEACHER TRAINING DESCRIPTION

A six-hour orientation session was held for the six teachers taking part in the experimental class at Mount Pleasant High School and Toll Gate High School. Background information on RI/BTC was provided and a videotape of selected portions of the pilots was presented to acclimate the teachers to the intended pedagogical techniques. Each teacher received a packet of instructional materials, a storyboard outline of the software, and the pre-tests and post tests. A period of time was allocated to familiarize the teachers with the content of the software, each teacher working with a research staff member at a computer. The session ended with a wrap-up and a review of the intended behavior of the teacher as facilitator.

PILOT AND MAY EXPERIMENT DESCRIPTION

The first pilot was conducted at The Wheeler School, an independent, coeducational, college preparatory day school in Providnece, Rhode Island. The fourteen (14) participating students comprised a first year biology class made up of 9th, 10th, and 11th graders. Genetics had not yet been presented in this course. Three classes were presented (the Taster Marriages was not included). All classes were videotaped and observed by RI/BTC staff.

The second pilot was held at Classical High School, a public, college preparatory school in Providence. The nineteen (19) 10th grade students were members of a first year biology class for above average students. Genetics had not yet been presented in this course at the time of the pilot. Three classes were conducted, including all four computer programs. All classes had observers; the first two classes were videotaped.

The first segment of the May experiment involved three teachers at Mount Pleasant High School, an inner-city school in Providence with a student body reflecting a racial and ethnic mix of Cambodians, Hispanics, Blacks and Caucasians. Five (5) classes, a total 115 9th grade students, were involved. Of the five physical science classes, one was high ability level, one was average, one was average to middle, and two were middle to low level. None of the students had received instruction in genetics during this course. The four-day trials were all videotaped and observed.

The second segment of the May experiment involved three teachers at Toll Gate High School in Warwick, Rhode Island. Each teacher had two 10th grade classes of Biology I. Four classes were of average ability, and two classes were for low ability students (6th grade reading level) placed in a special biology program. All the classes had previously received instruction in genetics. One class of each teacher was videotaped for the entire four-day unit. Observations were conducted of most of the classes.

DATA COLLECTION AND ANALYSIS

During our first year we collected data to assist us in the development of project materials and to provide information useful in answering the research questions. Because the project was a short term (4 days) intervention in the classroom, there was little reason to expect major changes in students skills in hypothesis testing. However, it was expected that the project should have a perceived impact on the teachers and students and an observable impact on the conduct of the class. We asked ourselves: 1) What happens in the classroom? 2) What is happening to students? and 3) What is happening to teachers? In order to collect data relevant to these questions, the following techniques were used.

Classroom Observations. In almost all of the pilots, one or more staff members observed each class. Staff members shared their impressions with the other staff members after the pilots and the May experiment were completed. The staff member observations were unstructured; no observation form or guide was used.

Teacher Pre-/Post Questionnaires. Teachers were given pre- and post questionnaires (Appendix D). These questions asked teachers about their teaching styles and their reactions to teaching in a setting in which the computer was the focus of attention.

Teacher Debriefings. The pilot and May experiment teachers attended a debriefing meeting with project staff. The staff asked questions focusing on teacher reactions to the teaching technique and to the materials.

Previewing Teachers' Response. The project materials were shown to a group of more than 30 biology teachers. Teachers were asked if they would use the materials in their teaching and for suggestions.

Student Post Questionnaire. The project developed a short, free response questionnaire for students that asked what students liked and disliked about the project and how the project classes were different and/or similar to their regular classes (Appendix E).

Student Pre-/Post Tests. The project developed alternate forms (blue and yellow) of a student pre/post test (Appendix F) focusing on hypothesis testing. These tests consisted of project developed items, and items selected from other tests including "Test of Enquiry Skills" (Fraser, 1979), "Test of Integrated Science Processes II" (Okey, 19?2), and the "Science Process Measure for Teachers" (AAAS, 1969). The purpose of these tests was to determine the viability of using paper and pencil examinations to measure changes in student abilities related to hypothesis testing. All students in the May pilot took these tests. A preliminary analysis of the results from the May pilot has been completed.

Video Tapes. All teachers were videotaped for 2-4 class periods. The video tapes have served a variety of purposes. All of the teacher questions on the video tapes have been transcribed and subjected to analysis. Videotapes from the first set of pilots were viewed by the entire staff. Some staff members have viewed tapes from the May experiment. A report on the level of teacher questions has been completed. A composite tape, showing lesson segments from all teachers of the May experiment has been prepared.

Each of these data sources was used as part of the project's retrospective analysis of the original research questions. The following section reports key findings related to our research questions.

RESEARCH FINDINGS

Four research questions of interest were stated at the beginning of our report. Three of these questions focused on the use of the computer in a whole class setting. The first research question asked if teachers would be receptive to a new pedogogical style in which the teaching pace was partially set by the materials. Teachers who used the materials and teachers who previewed the materials were two groups who helped us answer this question.

All of the teachers who used the materials stated during the teacher debriefings that they would use the technique again. The pilot teachers indicated that they did not readily adjust to using the materials, and that teaching a second class in this manner was much more comfortable than their first class. A few teachers indicated that they might modify the classroom setting from the way they used the materials in the trial.

Most of the teachers who previewed the materials indicated that they would use the materials in their classes. These teachers found the materials appealing because they required the students to engage in higher level thinking and to use the scientific method. About 1 in 8 of the teachers previewing the materials expressed reluctance to use the materials in their classroom. This reluctance was often tied to their preference for alternate materials or teaching strategies.

While teachers were found to be receptive to a science teaching approach in which the pace is partially set by the computer, several new parameters of concern developed during the pilot project. Data from teacher questionnaires, classroom observations, and student questionnaires raised concern that this mode of instruction may have extended for too long. Another item of concern was the number of entry/exit points in the software. Class periods were of different length during the pilots. Teachers found it difficult to determine appropriate ending points for a lesson that matched the class period. It appears that teachers are willing to use this instructional method occassionally, but not constantly. It also appears that teachers want the structure of the material flexible enough to adapt to their instructional setting.

The second research question asked if teachers would perceive their role in the classroom differently and would they modify their teaching sty .. Data from the teacher questionnaires, the teacher debriefings, the classroom observations and the videotapes provide information related to this question.

Teachers perceived that using the computer in the classroom altered their teaching style. They felt that using the computer in this manner was new and different. They indicated that they could tend to different classroom activities because the primary script for the lesson was programmed into the computer. Not all of the impact on teaching style was due to the structure of the lesson. Mechanical placement of the projector in the classroom, the darkening of the classroom, and the control of the computer were issues related to the technological equipment that teachers felt affected their teaching style.

A major effort went into examining teacher behavior in the classroom. The videotape record of pilot classes allowed for more careful examination of teacher behavior. One area examined was the cognitive level of questions used by teachers. Teachers asked from 35% to 51% high level inquiry (as categorized by Ladd and Andersen, 1970) questions. Research review by Balzer (1973), and Gall (1984) indicate that Biology teachers normally do not exceed 20-25% high level inquiry questions. We feel confident that the materials have helped to promote higher level questioning in the classroom.

The fact that teachers use numerous high level questions does not in itself indicate that our use of technology has been successful in altering the role of the teacher to that of a facilitator. Observers felt that few, if any, teachers used the computer to enable themselves to assume a facilitating role in the classroom. In spite of the fact that three of the teachers had been project staff members and all teachers had undergone training, they continued to overwhelm students with their talk and questions. They were uncomfortable giving students "wait" or "think" time or with exploring students ideas. Teachers asked an average of 235 questions in 150-160 minutes of instruction. We believe this rapid rate of questioning reflects ingrained teacher behavior. While previous research (Evans, 1973) has indicated that instructional behavior is resistant to modification, we had assumed that the computer software might instigate a change in the teacher role. The self-reports of teachers and the analysis of the teacher questioning style indicate that some shift in teacher role has occurred, but not nearly to the degree we had projected.

The third research question asked if computer-guided acivities in front of a class would be an effective focus of attention and address the targets of difficulty. Teacher reports, videotape reviews and classroom observations indicate that the computer can be used in the role envisioned. Strengths and weaknesses associated with this method are becoming clearer.

> The computer can be the focus of attention. Students can attend to the computer presentations, they can follow its instructions, and they can respect its judgments about their responses.
>
> Teachers are not immediately comfortable with the computer as

the center of attention. During the teacher debriefings, teachers noted that it was difficult to lead a class discussion when the students' eyes were directed at the projection screen.

The mode of instruction appears to promote student discussion and consideration of diverse views. Student questionnaire data indicated that this instruction differed from the normal science instruction they received in the amount of group discussion that occurred.

The computer as a focus of attention appears to lose its effectiveness over time. Continued use of this instructional methodolgy can lead to student boredom. To the student, each lesson appears the same. The lesson occurs in a darkened room. The computer projects and image on the screen, the class discusses an item, a choice is made, and the cycle is repeated. Teachers indicated that clever graphics, especially those with animation, can help to refocus student attention on the screen.

The sequence of lessons showed an increasing number of students who either lost attention or became marginally attentive to the lesson. While contextual factors may have been partially responsible for this (students knew they were not graded; students may have previously studied the content) the lesson structure may share responsibility. Much of the logic of the lessons develops in a long linear sequence. If a student misses or fails to understand an intermediate step in this linear sequence, the student may elect not to participate in the remainder of the lesson. It was our hope that giving part of the instructional role to the computer would free the teacher to attend to the issue of student participation. Little evidence of the teacher accepting this role was found.

The computer rather than the teacher dominated the structure, though not necessarily the delivery, of the lesson. The computer had the obvious control over the sequence of the material. Often teachers were heard to apologize for not "following" the computer script, e.g. asking a question one frame before the computer asked it. Lessons did not begin with the usual overview provided by the teacher. Moreover, the usual summary of closure activity presented by the teacher in most lessons formats was omitted from our lessons. Observations indicated that students were often following the lesson without knowing what their task was. At this stage we are considering which aspects of the whole group instruction are best left to the teacher.

The fourth research question asked if students would engage in inductive reasoning and develop skills in hypothesis testing. The long term purpose of our project is to develop student skills in this area. Throughout the instructional materials students were presented with hypotheses and asked if data support them or asked what data should be collected. This follows the advice of Moshman and Thompson (1981), who state, "one can best learn to test hypotheses by testing hypotheses."

To date we have used two types of data to determine if students are developing and using hypothesis testing skills. The first type of data come from the impressions acquired through classroom observations. The second type of data was gathered from the pre-/post test results. Each of these is described below.

The classroom observations have provided us with mixed feelings about our success in promoting hypothesis testing skills. Often we have observed instructional sequences in which neither the teacher nor the students appear to "get" the point of the sequence. In other cases we have seen students do a supurb job of recognizing the relationship of a set of data to an hypothesis. Overall, classroom observations indicate that students do not gain the hypothesis testing skills in this one set of lessons. Our current thinking is that students will have to encounter several examples of hypothesis testing throughout a biology course in order to develop these skills.

The pre-/post student test was developed to explore this method of assessing student skills. In short, nothing conclusive was learned from this test. Observations of students while they were taking the test made the observers question whether or not students took the test seriously enough. The results show that several items on the test were relatively easy for students. Items that were more difficult did not show any systematic change in student performance. We are left with the knowledge that any short instructional sequence has little likelihood of producing a recordable change by use of a pre-/post test of hypothesis testing. Future work in this area needs to consider other means of collecting data on student thinking. Alternatives, such as collecting student response data as they proceed through the materials, and post lesson interviews with students, are being examined.

CONCLUSIONS AND ISSUES

In looking at the two targets of difficulty that we formulated for our research, there are a number of conclusions we can draw at least for the present, and a number of issues that remain to be examined.

The first target of difficulty, that of engaging students in scientific reasoning, we narrowed to engaging students in hypothesis testing. First, we can say that, in the course of the experimental unit, we observed that students did practice hypothesis testing. Second, not all students could do this, and those who could not tended to drop out of the lesson. Third, we can conclude that extended practice is needed to accomplish a significant change in a student's scientific reasoning. Finally, from our own experience and the existing research, we know it is not easy to measure a change in student skill in this area.

Two issues must be addressed in our next steps. First the duration of the lesson may be critical in keeping students involved and in maintaining a freshness in the method of instruction. Second, there needs to be more of a separation between thinking about the lesson context, in this case genetics, and thinking about the scientific process. The metacognitive aspects of this unit, thinking about what makes an hypothesis consistent or inconsistent, may very well be overshadowed by the specificity of the questions asked by the computer concerning a genetic phenomenon. This second issue is bound up in the prevalent concern both students and teachers have about the immediate content to be understood, as opposed to the process of thinking about the content.

For the second target of difficulty, that of changing the role of the teacher in the classroom, we also have conclusions and remaining issues. First, we know that adopting the role of facilitator was extraordinarily difficult for all the teachers who tried it. Some teachers perhaps did not really understand what we intended, but even for those who were fully aware of the intent, putting that mode of instruction into practice proved terribly demanding and at times uncomfortable. We know that part of the normal instructional control attributable to the teacher in a class activity was transferred to the computer used as we have designed it. Teachers noted a loss in control both in structuring the class and in managing student behavior.

We know that the teacher's questioning of students during the classes included a high percentage of high-level inquiry questions. This result may have been a direct result of the presence of the technology and the instructional intervention of the software, or it may have been the result of heightened awareness on the part of teachers to ask higher level questions while they were being observed. In either case, we failed to observe other anticipated teacher behaviors associated with the role of the facilitator, such as the presence of wait time after questions were asked and the incorporation of student ideas into the selection of choices from the software.

Still an issue is the means by which we can effectively alter teacher behavior. One possible avenue of exploration includes a more comprehensive teacher training module that provides clearer models for teachers to follow. Another avenue would be to provide more elaborate materials to structure the lesson and the instructional methods, or to build into the software more guidance for the teacher. This issue leads to two further research questions. First, which teacher behaviors are most desirable and what changes need to occur to facilitate the development of scientific reasoning among students? Second, to what extent should the computer have an instructional role in the classroom, given the relative inflexibility and "blindness" of the current technology to react to individual class needs, and which instructional aspects are best left to the teacher, given the inevitable diversity of teacher styles?

In addressing both targets of difficulty there is much work to be done, work that may involve alternative software, work that may require using a shorter duration of instruction such as a single class period, work that examines different teaching strategies, and work that focuses the lesson and the teacher's attention to the metacognitive issues.

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Appendix A - SUGGESTED SOFTWARE REVISIONS

Based on observations of classes and teacher responses since the last revision of the software, the following revisions bear consideration before further use.

GENERAL

The representation of data, particularly percents, may be done more effectively if represented graphically, as with a single horizontal bar, than numerically.

Provide more convenient entry points to programs so that teachers may continue a program rather than to start over.

Create beginning and end points to the lessons to provide students with a sense of continuity and direction. Consider introductory and concluding frames comparable to a teacher's technique of giving an initial overview and a final wrap-up.

Include intermittent questions requiring written answers to give the researchers and the teacher a sense of what each student is thinking at that point in the lesson.

Design some kind of graphic routine for disposing of an hypothesis to emphasize the importance of concluding that the hypothesis is "inconsistent."

FILTER PAPER EXPERIEMNT

Teacher controlled delays during the filter paper administration.

Align data columns more accurately.

Emphasize "any" in Hypotheses I and II.

Emphasize "large" in Hypothesis III.

Format large numbers in population data with commas.

TASTER MARRIAGES

The opening hypothesis can not be disconfirmed and needs to be rephrased.

THE ISLANDS

Use the larger, clearer font for all text, reformatting all screens.

Provide clearer explanation initially of the subscript convention in designating generations.

Swap the position of Hypothesis I and II in the presentation for a smoother flow.

In the last frame change "theory" to "hypothesis."

THE TWO JARS

Repair the program bug so that the choice of all T's in the Father jar shows only T balls.
The multiple cases option must go faster.

Appendix B - TALLY SHEETS

# in Group	# of Tasters	# of Non-Tasters	% of Tasters	% of Non-Tasters	NOTES

Appendix C - HOMEWORK ASSIGNMENTS

HOMEWORK: The following are proposed assignments to be given after the Filter Paper Experiment, Taster Marriages, and The Islands. The purpose of these assignments is (1) to reinforce the material covered during that segment of the program and (2) to promote the use of numerical data to evaluate the validity of ideas and statements.

ASSIGNMENT 1: Filter Paper Experiment. This exercise should involve the use of tally sheets to see trends and establish hypotheses. Questions:

(1) Is there any difference between samples of large and small populations?

(2) Is there any difference in patterns of ratios that develop within populations? If so, using your tally sheets, justify your answer.

(3) If the data is consistent (or inconsistent), how will it affect your judgement of the validity of the hypothesis?

ASSIGNMENT 2: Taster Marriages. This exercise involves the three hypotheses listed in the Taster Marriages section. Questions:

(1) Are the three hypotheses mentioned in the Taster Marriages program consistent with your data?

(2) After you make your decision about your answer to question 1, justify your opinions about the validity of the hypotheses.

ASSIGNMENT 3: The Islands. This segment of the project ends with the confirmation of hypothesis #3. The object of this exercise is to justify that confirmation thru the use of information gathered on the tally sheet. Directions:

(1) Justify the validity of hypothesis #3 mentioned in The Islands program. It is stated as follows: Each offspring receives a factor from each parent; offspring with one taste factor are tasters. Use your tally sheet to show or reinforce the truth of your statements.

APPENDIX D - TEACHER PRE-/POST QUESTIONNAIRES

TEACHER QUESTIONNAIRE

PRE-UNIT

1. How would you characterize your teaching style?

2. What are your greatest strengths as a classroom teacher?

3. What areas of classroom teaching do you find most difficult?

4. If you could change one element of your teaching style, what would it be?

5. In what ways are your students exposed to the scientific method in your course? Please be as specific as you can.

6. What opportunities do your students have in the normal course of their experience in science to test hypotheses? Please be as specific as you can.

7. Have you ever used computers in your classroom before? Under what circumstances and for what purpose?

8. In your opinion, what makes a successful classroom?

TEACHER QUESTIONNAIRE

POST-UNIT

1. What did you like most about working with this unit?

2. What did you like least about working with this unit?

What elements of the unit caused you the most difficulty?

4. Do you think your students learned about hypotheses testing? Explain.

5. Did working with this unit affect your role as teacher in any way? Explain.

6. Did working with this unit affect student behavior and/or student learning in any way? Explain.

7. Would you consider using this unit again?

8. Please mark up your teacher's guide and return it to us. What suggestions do you have for changing any of the materials in the unit?

APPENDIX E - STUDENT POST QUESTIONNAIRE

STUDENT QUESTIONNAIRE

1. Describe two or three things you liked about this project.

2. What did you like least about this project? Why?

3. In what ways was this project different from and/or similar to your other classes?

4. What, if any changes, would you like to see in this project?

APPENDIX F - STUDENT PRE-/POST TESTS

Name:_______________________________

YELLOW TEST

The following questions are to determine your familiarity with scientific methodology. The test consists of several "sets" of information. Following each set of information are questions based on the information given.

Hypothesis:

I. If has been observed that crickets chirp more often during the spring, which is their mating season. A proposed hypothesis is that the increase in chirping frequency is caused by a sex hormone called testosterone.

The following conditions were established:

Ten separate cages each containing one male cricket were supplied with water in which different substances were dissolved. The temperature of the laboratory was set between 60 to 80 degrees Farenheit. A recorder was used to measure accurately the frequency of chirping of each cricket. Measurements were taken three times a day, namely, at 5:00, 9:00, and 11:00 PM.

It was found that all crickets (10 out of 10) receiving testosterone chirped more often than controls (with just water) when recorded at 9:00 and 11:00 PM. At 5:00 PM, in contrast, there was no significant difference in the chirping frequency of control and experimental (under testosterone) crickets. In this experiment, the temperature of the laboratory was kept at 75 degrees F.

Questions

Considering these results please answer each question by circling the appropriate word and give a brief reason for your choice.

1. Do you believe that the Hypothesis is ruled out by results?

Yes _____ No _____

Reason:

<u>NOTE</u>: The following experiments are <u>in addition</u> to the first one, that is, they do not exclude previous results.

2. When another experiment was conducted at a lower temperature (60 degrees F) a different result was obtained. The crickets given testosterone did not chirp more frequently than the controls. This is true at any time. Do you believe that the Hypothesis is ruled out by these new results?

   Yes _____ No _____

   Reason:

3. Still another result was obtained when a larger dose of testosterone was given to the experimental crickets. In this case, the chirping frequency of the crickets under testosterone was considerably less than that of controls. This inhibitory effect of testosterone was observed at 5:00, and 9:00, but not at 11:00 PM. Do you believe that these results rule out the Hypothesis?

   Yes _____ No _____

   Reason:

4. On a scale of 1 to 5 indicate whether you find the questions 1 - 3 easy or difficult to answer?

   1 ——— 2 ——— 3 ——— 4 ——— 5

   Easy Difficult

   Reason:

5. Indicate on a scale of 1 to 5 whether you find that a previous knowledge of biology is necessary to answer the questions 1 - 3.

   1 ——— 2 ——— 3 ——— 4 ——— 5

   No Knowledge Considerable Knowledge

   Reason:

II. After reading the information and the table below, answer questions (6 - 9).

The following table gives some data about the time it takes for various mixtures to freeze after being placed in a freezer.

Mixture placed in freezer	Time to freeze
A. 100 ml water and 0 grams of salt	40 minutes
B. 100 ml water and 20 grams of salt	70 minutes
C. 100 ml water and 20 grams of sugar	70 minutes
D. 100 ml water and 30 grams of alcohol	100 minutes
E. 100 ml water and 30 grams of sand	40 minutes

For questions 6 - 9, indicate whether the data in each row supports or does not support the following hypothesis about time it takes to freeze by checking the appropriate box.

Hypothesis: Liquids freeze more slowly when they contain dissolved materials.

	Support the Hypothesis	Do Not Support the Hypothesis	Does Not Provide Enough Information
6. Data from A	☐	☐	☐
7. Data from B	☐	☐	☐
8. Data from C	☐	☐	☐
9. Data from D	☐	☐	☐
10. Data from E	☐	☐	☐

III. Konrad Lorenz was very interested in Mallard ducklings (baby ducks). In particular, he liked to watch the way ducklings follow the mother duck around. To explain this he had the following idea:

Idea: The quacking of the mother duck is what attracts Mallard ducklings to her.

To see if his idea was right, Konrad Lorenz made some observations. Some of these observations suggest that Konrad Lorenz's Idea is true and others suggest that it is false. Some observations tell us nothing about whether the idea is true or false. Use these observations to answer Questions 11-15 by checking the appropriate box.

11. Observation I. Knorad Lorenz made a noise like a Mallard duck and the ducklings followed him.

CHOOSE ONE

☐ Suggests idea is true.

☐ Suggests idea is false

☐ Not enough information to help decide whether true or false.

12. Observation II. A dog barked at the ducklings and they ran away.

CHOOSE ONE

☐ Suggests idea is true.

☐ Suggests idea is false

☐ Not enough information to help decide whether true or false.

13. Observation III. A white farmyard duck quacked like a Mallard duck and the ducklings followed her.

CHOOSE ONE

☐ Suggests idea is true.

☐ Suggests idea is false

☐ Not enough information to help decide whether true or false.

14. Observation IV. A duck, which could not quack, hatched some Mallard eggs and the ducklings followed her.

CHOOSE ONE

☐ Suggests idea is true.

☐ Suggests idea is false

☐ Not enough information to help decide whether true or false.

15. Observation V. Konrad Lorenz made a noise like a rooster and the ducklings followed him.

CHOOSE ONE

☐ Suggests idea is true.

☐ Suggests idea is false

☐ Not enough information to help decide whether true or false.

IV. Select the best answer to each question 16-20.

16. Joe wanted to find out if the temperature of water affected the amount of sugar that would dissolve in it. He put 50 ml. of water into each of four identical jars. He changed the temperatures of the jars of water until he had one at 0 degrees C, one at 50 degrees, one at 75 degrees C, and one at 95 degrees C. He then dissolved as much sugar as he could in each jar by stirring.

    What is the hypothesis being tested?

    A. The greater the amount of stirring, the greater the amount of sugar dissolved.

    B. The greater the amount of sugar dissolved, the sweeter the liquid.

    C. The higher the temperature, the greater the amount of sugar dissolved.

    D. The greater the amount of water used, the higher the temperature.

17. A police chief is concerned about reducing the speed of autos. He thinks several factors may affect automobile speed.

    Which of the following is a hypothesis he could test about how fast people drive?

    A. The younger the drivers, the faster they are likely to drive.

    B. The larger the autos involved in an accident, the less likely people are to get hurt.

    C. The more policemen on patrol, the fewer the number of auto accidents.

    D. The older the autos, the more accidents they are likely to be in.

18. A study was done to see if leaves added to soil had an effect on tomato production. Tomato plants were grown in four large tubs. Each tub had the same kind and amount of soil. One tub had 15 kg: or rotted leaves mixed in the soil and a second had 10 kg. A third tub had 5 kg. and the fourth had no leaves added. Each tub was kept in the sun and watered the same amount. The number of kilograms of tomatoes produced in each tub was recorded.

    What is the hypothesis being tested?

    A. The greater the amount of sunshine, the greater the amount of tomatoes produced.

    B. The larger the tub, the greater the amount of leaves added.

    C. The greater the amount of water added, the faster the leaves rotted in the tubs.

    D. The greater the amount of leaves added, the greater the amount of tomatoes produced.

19. Ann has an aquarium in which she keeps goldfish. She notices that the fish are very active sometimes but not at others. She wonders what affects the activity of the fish. What is a hypothesis she could test about factors that affect the activity of the fish?

    A. The more you feed fish, the larger the fish become.

    B. The more active the fish, the more food they need.

    C. The more oxygen in the water, the larger the fish become.

    D. The more light on the aquarium, the more active the fish.

20. Jim thinks that the more air pressure in a basketball, the higher it will bounce. To investigate this hypothesis he collects several basketballs and an air pump with a pressure gauge. How should Jim test his hypothesis?

    A. Bounce basketballs with different amounts of force from the same height.

    B. Bounce basketballs having different air pressures from the same height.

    C. Bounce basketballs having the same air pressure at different angles from the floor.

    D. Bounce basketballs having the same amount of air pressure from different heights.

2. Imagine that the experiment had a different outcome. Assuming that every one of the bottles (i.e., heated and not heated) showed turbidity and also large numbers of germs. With this change would you then believe that the Hypothesis is ruled out?

Yes _____ No _____

Reason:

3. If all bottles would have been clear (no germs), at the end of the experiment, would the Hypothesis be ruled out?

Yes _____ No _____

Reason:

4. On a scale of 1 to 5 indicate whether you find the questions 1 - 3 easy or difficult to answer?

1————2————3————4————5

Easy Difficult

Reason:

5. Indicate on a scale of 1 to 5 whether you find that a previous knowledge of biology is necessary to answer the questions 1 - 3.

1————2————3————4————5

No Knowledge Considerable Knowledge

Reason:

II. After reading the information and the table below, answer questions (6 - 9).

The following table gives some data from a large group of people about how often color blindness occurs in the children of parents who are or are not colorblind:

	Sons	Daughters
A. When both father and mother are color-blind, color blindness in the children occurs as follows:	all	all
B. When mother is colorblind and father is not color-blind, color blindness in the chldren is as follows:	all	none
C. When father is colorblind and mother is not colorblind, color blindness in the chldren is as follows:	0.25	0.25
D. When neither father nor mother is colorblind, color blindness in the children is as follows:	0.25	none

For questions 6 - 9, indicate whether the data in each row support or do not support the following hypothesis about colorblindness by checking the appropriate box.

Hypothesis: If one or both parents are colorblind, at least half of the children will be colorblind.

	Support the Hypothesis	Do Not Support the Hypothesis	Does Not Provide Enough Information
6. Data from A	☐	☐	☐
7. Data from B	☐	☐	☐
8. Data from C	☐	☐	☐
9. Data from D	☐	☐	☐

III. A long time ago, scientists were arguing about what happens during digestion in turkeys. A scientist named Reaumur had the following idea:

<u>Idea</u>: Digestion is a chemical process.

To see if he were right, Reaumur bought some glass beads with holes. He inserted grains of oats into the holes, expecting to see the oats dissolve and disappear from the holes if digestion were chemical and expecting to see the oats stay whole if digestion were not chemical but mechanical. He fed the glass beads to his turkeys. Below are some possible observations that he might have made. Some of these observations suggest that it is false. Some observations tell us nothing about whether the idea is true or false. Use these observations to answer 10 - 15 by checking the appropriate box after each observation.

10. <u>Observation I</u>. The turkeys did not seem to mind eating glass beads.

CHOOSE ONE

☐ Suggests idea is true.

☐ Suggests idea is false

☐ Not enough information to help decide whether true or false.

11. <u>Observation II</u>. Glass beads in the droppings contained whole grains of oats.

CHOOSE ONE

☐ Suggests idea is true.

☐ Suggests idea is false

☐ Not enough information to help decide whether true or false.

12. Observation III. Glass beads in the droppings were empty of oats.

CHOOSE ONE

☐ Suggests idea is true.

☐ Suggests idea is false

☐ Not enough information to help decide whether true or false.

13. Observation IV. No glass beads or oats were found in any droppings.

CHOOSE ONE

☐ Suggests idea is true.

☐ Suggests idea is false

☐ Not enough information to help decide whether true or false.

14. Observation V. No glass beads were found in any droppings, but when turkeys were killed and opened, fine glass powder was found inside the stomach.

CHOOSE ONE

☐ Suggests idea is true.

☐ Suggests idea is false

☐ Not enough information to help decide whether true or false.

15. Observation VI. No glass beads or oats were found in any droppings, but when turkeys were killed and opened, find glass powder was found inside the stomach.

C H O O S E / O N E

☐ Suggests idea is true.

☐ Suggests idea is false

☐ Not enough information to help decide whether true or false.

IV. Select the best answer to each question 16 - 20.

16. Marie wondered if the earth and oceans are heated equally by sunlight. She decided to conduct an investigation. She filled a bucket with dirt and another bucket of the same size with water. She placed them so each bucket received the same amount of sunlight. The temperature in each was measured every hour from 8:00 am to 6:00 pm. Which hypothesis was being tested?

   A. The greater the amount of sunlight, the warmer the soil and water become.

   B. The longer the soil and water are in the sun, the warmer they become.

   C. Different types of material are warmed differently by the sun.

   D. Different amounts of sunlight are received at different times of the day.

17. A greenhouse manager wants to speed up the production of tomato plants to meet the demands of anxious gardeners. She plants tomato seeds in several trays. Her hypothesis is that the more moisture seeds receive the faster they sprout. How can she test this hypothesis?

   A. Count the number of days it takes seeds receiving different amounts of water to sprout.

   B. Measure the height of the tomato plants a day after each watering.

   C. Measure the amount of water used by plants in different trays.

   D. Count the number of tomato seeds placed in each of the trays.

18. Susan is studying food production in bean plants. She measures food production by the amount of starch produced. She notes that she can change the amount of light, the amount of carbon dioxide, and the amount of water that plants receive. What is a testable hypothesis that Susan could study in this investigation?

    A. The more carbon dioxide a bean plant gets the more starch it produces.

    B. The more starch a bean plant produces the more light it needs.

    C. The more water a bean plant gets the more carbon dioxide it needs.

    D. The more light a bean plant receives the more carbon dioxide it will produce.

19. Mark is studying the effect of temperature on the rate that oil flows. His hypothesis is that as the temperature of the oil increases it flows faster. How could he test this hypothesis?

    A. Heat oil to different temperatures and weigh it after it flows out of the can.

    B. Observe the speed at which oil at different temperatures flows down a smooth surface.

    C. Let oil flow down smooth surfaces at different angles and observe its speed.

    D. Measure the time it takes for oil of different thicknesses to pour out of the can.

20. A farmer wonders how he can increase the amount of corn he grows. He plans to study factors that affect the amount of corn produced. Which of these hypotheses could he test?

    A. The greater the amount of fertilizer the larger the amount of corn produced.

    B. The greater the amount of corn, the larger the profits for the year.

    C. As the amount of rainfall increases, the more effective the fertilizer.

    D. As the amount of corn produced increases, the cost of production increases.