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ABSTRACT

Interactive Multi-Media Exercises (IMMEX) is a technology-based learning and assessment tool designed to integrate curricular content and problem-solving skills into real world scenarios. IMMEX inherits much of its structure from case-based and problem-based learning models and provides teachers with quantifiable, visual feedback on student problem-solving performances so that interventions can be acutely informed and immediate. While most teachers utilize the most basic performance indicators provided by IMMEX for measuring student progress, richer analytic tools have shown performance nuances such as: (1) significant correlation between problem-solving and (some) standardized test scores; (2) evidence that males and females approach problem-solving differently; and (3) strategic trends in problem-solving. The classroom integration of technology is supported by extensive professional development activities including workshops where teams of teachers, students, and university faculty write IMMEX cases. (Contains 25 references, 3 figures, and 2 tables.) (Author/SLD)

Tracing The Development, Transfer, and Persistence Of Problem Solving Skills

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ABSTRACT-

IMMEX is a technology-based learning and assessment tool, designed to integrate curricular content and problem-solving skills into real world scenarios. IMMEX inherits much of it's structure from case-based and problem-based learning models and provides teachers with quantifiable, visual feedback on student problem-solving performances so that interventions can be acutely informed and immediate. While most teachers utilize the most basic performance indicators provided by IMMEX for measuring student progress, richer analytic tools have shown performance nuances such as 1) significant correlations between problem-solving and (some) standardized test scores, 2) evidence that males and females approach problem-solving differently, and 3) strategic trends in problem-solving. The classroom integration of technology is supported by extensive professional development activities including workshops where teams of teachers, students, and university faculty author IMMEX cases.

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Case-based and problem-based learning have been used as effective instructional strategies in professional schools for several decades (Elstein 1993; Kolodner 1993). These approaches have been attractive and effective not only for their inherent motivational factors and realistic contexts but also for the unique perspective they provide about student learning (Barrett and Depinet 1991). While these approaches also align with reform movements in math and science (See for example: Goals 2000 (1994); The National Commission on Excellence in Education (1983); American Association for the Advancement of Science [AAAS], Project 2061 (1993); National Research Council (1996)), the incorporation of case-based learning into the K-12 curriculum has been infrequent, particularly in schools with high student diversity. This is mainly due to the extensive and systemic curricular reorganization needed before implementation of such learning approaches can become widespread. The challenges in this reorganization process are physical (the construction of the materials), logistical (implementation and integration schemes), and organizational (re-aligning curricula, professional development and evaluation approaches); i.e. the elements in the diffusion of most innovations (Valente 1995; Friedman et. al.)

Computer technologies hold promise for accelerating the adoption of alternative learning and assessment modes in education. Twelve years ago IMMEX (Interactive Multi-Media Exercises) was developed for teaching and assessing the diagnostic skills of medical students (Stevens 1991). IMMEX software is a set of problem-solving authoring and performance data collection and analysis tools, which inherits much of its theory from case-based (Schank, 2000) and problem-based learning. Through vigorous community engagement activities and extensive professional development workshops, these software tools have been successfully, and widely, incorporated into primary and secondary school classrooms (Palacio-Cayetano et. al. 1999).

Overview of IMMEX

Authoring teams made up of teachers, students and university faculty, use IMMEX software to develop snapshots of complicated and dynamic systems, in both science and non-science subjects, that pose situations for students to resolve by viewing and causally linking data. The data variables are loosely structured as menu items, or button links, and can be selected in any sequence. These items, and the problems posed, constitute what is called the "problem space" that defines the playing field for students and researchers.

Each case opens with a prologue and students use the embedded information to frame the problem and to begin forming hypotheses. Then, depending on prior knowledge and experience, they begin to search the problem space for items that support or refute their current theory. To align these tasks with student abilities, these spaces, which contain many solution paths, have a finite structure emphasizing the development of linkages among problem space variables. Most cases also contain a solution to the problem. While Hart (1994) and others have expressed concerns regarding problems with single solutions, our five-years of experiences shows no evidence from student performances, notes associated with problem-solving or survey data, that students are viewing the problem-sets through the small lens of "a single right answer". This, in part, may be due to the broad perspective of a problem space afforded by IMMEX, and by the large number of multiple instances, or clones (sometimes as many as 60), of each case within the different problem-sets.

We, and others, have also learned that for software to be meaningfully integrated and aligned with learning goals, strong professional development supports are a vital part of the educational technology equation (National Research Council 1991). Also, Johnson (1999) asserts that in order for technology to have a positive impact on student achievement, computer use must not be a separate program that students attend only one-half hour a week.

To address these multiple educational dimensions, the IMMEX Project is developed around three broad frameworks.

The first framework describes the structure of extensive inservice and preservice professional development programs focusing on the creation of case-based software by teams of teachers and academic professionals. The cases are relevant and often real-world tasks that are appropriate for, and engage the majority of students. To date, over 400 teachers have participated in these, and other professional development activities and have created hundreds of cases for their classrooms. The development process is guided and validated by close associations with content experts and different professional societies (American Association of Immunologists, American Physical Society) so that state and national standards alignment is not only achieved, but in many cases, surpassed.

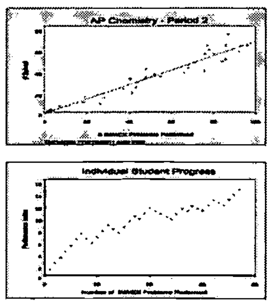
The details of the case development process (including pedagogical issues), the definition of problem spaces, identification of learning goals, standards alignment, etc. are discussed by Palacio-Cayetano, et al. (manuscript in preparation). Evaluation studies have indicated that students (and teachers) perceive IMMEX as a way of fostering the integration of information, rather than the learning of facts. Therefore, providing students with core content prior to using the problem-sets, has shown to be the most effective classroom practice. Each case, however, is complete in that all the information needed to solve it is embedded within the problem space including extensive library resources and explanatory aids.

The development of curricular software that encompass broad learning, assessment, and research goals is complex and must address the concerns of multiple audiences including students, parents, teachers, administrators, educators, policy makers, etc. The second IMMEX framework helps define classroom implementation and curricular integration schemes that will maximize student learning and scaffold teachers in their use of technology and case-based reasoning. This framework also helps refine in cost/benefit terms, how the integration of curriculum into technology, with the full range of supports, can enrich the curricular priorities for schools and districts.

The third framework defines the role of student performance data in the discovery of learning paths of students in a case-based reasoning environment. Three-levels of reporting tools provide teachers and researchers continual performance information as well as cognitive and metacognitive insights into their students thinking. The elements of this framework are the main focus of this paper and are summarized in Figure 1.

IMMEX Online Performance/Progress Reporting Level 1:

Classroom and Individual Student Progress Measures



Description:

The cumulative class performance plots the percent of IMMEX problems solved against the number of problems performed. Teachers can follow the case solved rate over time.

Individual student progress is measured by plotting the Performance Index (a number calculated by plotting the number of problems solved against the Percent solved) by the total number of problems solved. Peaks and valleys demonstrate where students are having successes and difficulties respectively.

Uses:

Immediate feedback on class and student performance.
Links problem-solving efficiency to other metrics (AP, grades).
Helps frame research/equity issues (gender, language, etc.).

(Figure 1.)

Tracing the Development of Problem Solving Skills

We have developed multiple measures from the rich data generated in IMMEX cases that enable teachers, students and educators to follow individual student and classroom progress at different degrees of detail. For instance, a teacher who assigns cases as out-of-class activities would like to know on a daily basis which students are performing the cases and how well they are doing (proficiency). Teachers may also want a quick check to compare differences in performances between classes. These proficiency measures constitute the Level 1 of IMMEX data reporting (Figure 1). Online, teachers can view a graph plotting the number of problems completed vs. the number solved and further scroll down to look at this ratio for individual students. They can then hyperlink to individual students and view individual student progress throughout the course, seeing what problem-sets they struggle with (drops in the curve) and those where they enjoy success (peaks).

While these reporting tools are useful for teachers they can also contribute to the research base by providing a performance measure for correlation studies. For instance, in two AP chemistry classes, the correlations between problem-solving performance and prior STAR science tests are low, but are better for course grades and AP scores (Table 1).

Problem Solving Correlations

		Percent Solved (Year-long)
Percent Solved (Year-long)	Pearson Correlation	1.000
	Sig. (2-tailed)	.
	N	55
STAR Reading	Pearson Correlation	.323*
	Sig. (2-tailed)	.018
	N	53
STAR Math	Pearson Correlation	.274*
	Sig. (2-tailed)	.047
	N	53
STAR Science	Pearson Correlation	.114
	Sig. (2-tailed)	.417
	N	53
Mid-Term Grade	Pearson Correlation	.558**
	Sig. (2-tailed)	.000
	N	46
Multiple Choice Exam	Pearson Correlation	.445**
	Sig. (2-tailed)	.001
	N	52
Overall Class Grade	Pearson Correlation	.389**
	Sig. (2-tailed)	.004
	N	53
Advanced Placement Score	Pearson Correlation	.584**
	Sig. (2-tailed)	.000
	N	53
Percent Solved (Exam)	Pearson Correlation	.316*
	Sig. (2-tailed)	.027
	N	49

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level

(Table 1. Correlation of Problem-Solving Efficiency (% of cases solved) With Other Performance Indicators.)

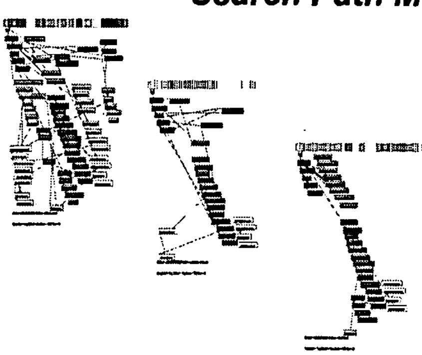
We have also seen gender differences emerge out cumulative percentage data collected from a yearlong, homework-based, implementation plan. Males and females performed the same number of problems (Males = 36 ± 14 Females = 42 ± 11), and solved the same number of problems (Males = 61± 8% Females = 57 ± 12%) however, the correlation between course grades and problem-solving proficiency was greater for girls (Males .235 p=.221, Females .61, p=.002). In fact, the course grades and the IMMEX problem-solving performance account for nearly 70% of the variance in females AP performance. Males were more variable in their performances, with grades and problem solving only accounting for 40% of the AP score variance. These gender affects are explored further in Paek et al. (manuscript in preparation).

Level 1 reporting features are therefore useful for providing a quick snapshot of student performance. Often, however, teachers wish to dig deeper into the foundations of their students thinking and the search path mapping features of Level 2 data reporting equip teachers with the tools to do so.

While students engage in problem solving, the sequence of their actions is recorded into a log from which we generate visual maps of their search through each problem space. These maps visually display every data item selected by the student (represented by the color-coded rectangles arranged by content, concepts or types), the sequence in which the information was selected (indicated by the line traveling from the left corner to the center of the rectangle), and the time spent on each concept. (See Figure 2). Because these maps are rich in information, teachers can, and do use them in multiple ways. For teachers who are authors, these maps provide a validity check to ensure that the case is performing as intended. Also, classroom interventions are suggested by group maps that compare the strategies the students who solve or miss the case.

IMMEX Online Performance/Progress Reporting Level 2:

Search Path Mapping of Student Strategies



Description:

Displays each test selection chosen during a case as a colored rectangle and connects the sequence with a line. A literal map of a student's thinking.

Uses:

Visualizes student problem-solving approaches.
Repeat performances document improvement.
Serves as an artifact for student reflection.
Provides a structure for scoring rubrics.

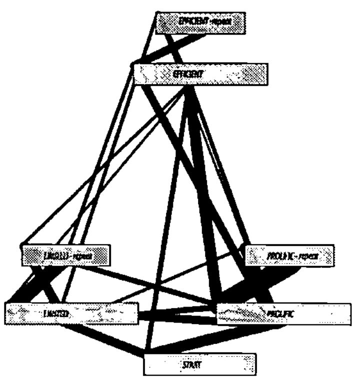
(Figure 2.)

By comparing earlier maps to later ones, a teacher can judge refinements of problem solving approaches over time as shown in Figure 2. Other teachers provide these maps to students to encourage reflection and have them write essays analyzing their own progress (Lawton 1998). Search path maps are particularly important for examining the more metacognitive aspects of problem-solving such as persistence, elimination of alternative hypotheses, efficiency, confidence and certainty, and related professional development activities focus on this type of educational intervention. Lastly, these Level 2 maps provide the artifacts for developing problem-solving scoring rubrics and for revealing the nature of the clustering of performances.

Level 3 of IMMEX data reporting seeks to link search path maps with classroom interventions to improve learning. Examination of thousands of student performances in many domains and across multiple grade-levels of education (elementary through medical school) has indicated that many search strategies/approaches can be applied while solving IMMEX problems. Students differentially use these strategies, often unconsciously (Reder & Schnn 1996), and through this use, they can develop higher order strategies.

IMMEX Online Performance/Progress Reporting Level 3:

Strategy Transition Diagrams



Description:

The "Limited" strategy group (left) is represented as the pink rectangles,"Prolific" (right) by the yellow, and "Efficient" (top) by the green. The groups are defined by scoring rubrics or neural network clustering and the thickness of the lines proportionaly indicates transitions among strategy groups upon repeat testing.

Uses:

Provides probabilistic inferences about student progress.
Suggests points of intervention.
Documents effects of interventions.
Allows classroom progress comparisions

(Figure 3.)

In following these strategies over time, it has become apparent that, for each problem-set, there are transitional states that students may (or may not) pass through as they develop expertise. (Figure 3.) Level 3 data analysis demonstrates how students arrive at, and depart from these states enabling researchers to use this information in a predictive fashion. The key component of this research is the development of valid and rapid procedures for classifying the strategies revealed by the search path maps. Categories of problem-solving states are being determined through both rubrics (analysis of student search path maps) as well as natural clustering of key components of the problem-solving process by artificial neural networks. Each provides a different level of contextual information and granularity and can often be productively combined.

Neural network clustering is an automated technique where the sequence of student actions during problem solving is used as input to unsupervised artificial neural networks that perform classifications based on these sequences. We have shown this approach applicable to both simple and complex problem-solving situations (Stevens and Najafi 1993; Casillas et. al. 2000).

The second, more traditional approach involves the development of scoring rubrics by teams of teachers, educators, content experts and case authors. In this procedure, performance guidelines are first established and agreed upon based on the case and representative student work. Next, scoring teams use these rubrics to rate large numbers of search path maps and the rubrics are refined for performances where the inter-rater reliability is low. This approach can be guided by neural network groupings as a starting point for in depth performance analysis, observing problem-solving trends, and the transitioning between states over time. Thus rubrics incorporate "person-specific" key elements, while neural network provides strategic clustering without the associated interpretative information.

An example by Vendlinski (2000) describes a combination of these approaches. He used artificial neural networks to identify common strategies in over 800 student performances by using a technique similar to ones described in Klahr and MacWhinney (1997). Based on the resulting strategies, the amount of information a student reviewed and the likelihood that the strategy was successful, he grouped the strategies into three general categories. Category 1 strategies were termed "limited" and contained performances where students had only gathered enough information to do little more than guess at an answer. For the most part, these students were unlikely to solve the problem. Category 2 strategies were termed "prolific" and consisted of performances where students had accumulated more than enough information to solve the case, but were unable to convert the information they had into a successful solution to the problem. Category 3 strategies were labeled "efficient" and most often resulted in a successfully solved problem. This is similar to a finding by Maker (1994) that suggests, "high" competence is the ability to solve the most complex (or the most simple) problems in the most efficient, effective or economical ways." The student performances were then ordered and plotted so transitions between categories could be seen. As shown in Figure 3, a similar number of students began with limited or with prolific strategies, while fewer students began with efficient strategies. Most students who begin with a limited strategy, remain there (despite little success at solving problems). These students appear unlikely to improve their problem-solving abilities without intervention. While a number of students who begin with prolific strategies do transit to a more effective strategy, most seem to fall back into using more profuse strategies in subsequent attempts to solve IMMEX cases. These students might also profit from problem-solving interventions. Lastly, most students who begin solving problems efficiently continue to use similar strategies in subsequent cases. These trends are even more apparent when the first strategy type chosen by a student is juxtaposed against the most frequent strategy type the student used to solve problems. As shown in Table 2, the first strategy type is significantly correlated with the most frequent strategy type chosen by the student.

	Category 1 strategies on most problems	Category 2 strategies on most problems	Category 3 strategies on most problems
Category 1 strategy on first problem	30	8	6
Category 2 strategy on first problem	5	35	8
Category 3 strategy on first problem	5	9	23

(*Table 2.* This table compares the category of the strategy a student used to solve his or her first qualitative Chemistry IMMEX problem to the category of the strategy a student used most often to solve different versions of the same problem. There is significant statistical evidence ($\chi^2 = 70.5$; d.f. = 4; p<.000) to conclude that this effect is not random.)

Using this approach we can not only identify students who successfully make the transition from less successful to more successful strategies (and perhaps why), but also the probabilities that students will make such transitions without teacher intervention. When interventions are attempted, we can use this information to test the effectiveness of those interventions and individual student improvement. Such a tool also provides important feedback to educators and allows them to document the overall effects of their teaching approaches and methods.

The power of this approach is that probabilities can now be derived for students at each strategy level and that interventions can be tested for their effect on changing these probabilities where appropriate. These diagrams also provide a means for documenting effects of overall classroom teaching approaches and methods.

Conclusions:

At a recent meeting Dr. Linda Roberts of the Department of Education remarked that "There is no longer an interest in focusing on "technology for technology sake", it is not about the computers or the software, it is about how they are utilized for learning" (L. Roberts, 2000).

The IMMEX Project, by virtue of its close teacher partnerships and comprehensive frameworks for developing and implementing software, is beginning to construct a model for the successful local production and utilization of technology-based learning systems.

Much of the impetus for this development, however, resides in the shared understanding that the development of rich models of student performance and progress in different disciplines and at different levels of education, represents the next stage in the evolution of learning technologies. To learn more about The IMMEX Project implementation and research methodologies, to view the problem-sets available, or for contact information, visit www.immex.ucla.edu.

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