Music Prodigy annotated Education research citations

Contents

Computerized teaching and tutorial combined with mastery challenge in an organized curriculum

§1- Dannenberg, Sanchez, Joseph, Joseph, Saul, and Capell, "Results from the Piano Tutor Project," in *Proceedings of the Fourth Biennial Arts and Technology Symposium*, pp. 143-150. Connecticut College, Connecticut (March 1993).

The Piano Tutor was perhaps the first intelligent tutor for psycho-motor skills. Students in a pilot study achieved first-year piano proficiency with an average of under 20 hours of instruction.

Link:
http://www.cs.cmu.edu/~rbd/papers/ptutor/conpt.pdf

§2- Koedinger, K. R., Anderson, J. R., Hadley, W. H., & Mark, M. A., "Intelligent tutoring goes to school in the big city," in *Proceedings of the 7th World Conference on Artificial Intelligence in Education*. Washington, DC (August 1995).

The Pittsburgh Urban Mathematics Project (PUMP) used an intelligent computer tutor to teach 9th grade algebra to 470 students in public schools, improving student performance over a control group by 15% and by 100% on tests targeting the PUMP objectives.

Link:
http://act-r.psy.cmu.edu/papers/231/jaied97.pdf_2.pdf

Research report on mastery challenge

§3- Yu, Christina, "Five myths about mastery learning," in *The Knewton Blog: Knewton Adaptive Learning*. Washington, DC (November 2011).

Knewton Adaptive Learning is developing and installing computerized learning systems currently focused on elementary school mathematics. This blog entry deals specifically with one of the key strengths of their teaching method.

Link:
http://www.knewton.com/blog/knewton/adaptive-learning/2011/11/18/5-myths-about-mastery-based-learning/

Research report on music education as part of general education

§4- Staff, "Arts and Education," in *Research Brief of the Kronkosky Charitable Foundation*. San Antonio, TX (January 2012).

A broad base of research surveyed showing that an education in various types of art can have positive effects for children, in particular, studies in Texas reporting advances in SAT scores for music students. The brief includes twenty-one citations and references.

Link:
http://www.kronkosky.org/research/Research_Briefs/Arts%20and%20Education%20January%202012.pdf

Results from the Piano Tutor Project[1]

Roger B. Dannenberg, Marta Sanchez, Annabelle Joseph, Robert Joseph, Ronald Saul, Peter Capell

Carnegie Mellon University
Pittsburgh, PA 15213
email: dannenberg@cs.cmu.edu

ABSTRACT

The Piano Tutor combines an expert system and multimedia technology to form an interactive piano teaching system. Important elements of the Piano Tutor are: (1) the use of score-following software to interpret student performances, (2) the use of extensive multimedia to create a natural dialog with the student, (3) an expert system to analyze student mistakes and give pertinent multimedia feedback, and (4) the use of Instructional Design theory to develop an extensive curriculum that can be tailored automatically to individual student needs. Results from a preliminary assessment of the Piano Tutor are presented.

KEYWORDS: Intelligent Tutor, Multimedia, Instructional Design, Interactive, Accompaniment

1. Introduction

The Piano Tutor Project began as an ambitious project to integrate multimedia [Blattner 92] and intelligent tutoring [Wenger 87, Sleeman 82] technologies with a sound and extensive piano instruction curriculum. Our goal, established by Drs. M. Sanchez and A. Joseph, was to use computers and multimedia technology to support piano instruction for beginners. After three years of concentrated effort, the project produced a working prototype that has achieved international recognition as the state-of-the-art in computer-based music instruction systems. Although the Piano Tutor research project has ended, a commercial implementation of the Piano Tutor and related technologies is now in progress.

In a pilot study, the Piano Tutor was used to teach piano to a group of 18 subjects. This

---

[1]Published as: Dannenberg, Sanchez, Joseph, Joseph, Saul, and Capell, ‘‘Results from the Piano Tutor Project,’’ in ***Proceedings of the Fourth Biennial Arts and Technology Symposium***, Connecticut College, (March 1993), pp. 143-150.

study confirmed our belief that a computer-based instruction system could be very effective in teaching a substantial body of musical knowledge. Our subjects enjoyed using the Piano Tutor, they learned at a rapid pace, and they could transfer their new skills to sight-reading and performance tasks in standard piano instruction books.

There have been at least four noteworthy achievements. The first is the application of score-following technology in an instructional system. The Piano Tutor can follow a student's (polyphonic) piano performance [Bloch 85, Dannenberg 88], turn pages automatically, and synchronize an accompaniment. The ability to follow student performances is important to understanding, analyzing, and interacting with students. Automatic page turning is an important technique for presenting music to students via computer screen, and accompaniment gives students ensemble experience.

The second achievement is the integration of an extensive multimedia presentation system to create a natural dialog with the student. [Dannenberg 92] The Piano Tutor uses a combination of video, music notation, digitized voice, synthesized music, and graphics, all controlled by an expert system in response to student performances. Multimedia allows the Piano Tutor to effectively convey the visual, aural, and basic technical skills necessary for piano performance.

Our third achievement is the development of an expert system component for the Piano Tutor. [Dannenberg 90a, Dannenberg 90b] The expert system analyzes student performances and gives pertinent feedback to guide the student. Initially, the student is encouraged to correct mistakes by trying again, but if this fails, the system automatically proposes simpler tasks that help the student concentrate on the source of difficulty. If problems persist, the system assumes that the the student needs to strengthen previously learned skills. Again, the system identifies relevant tasks for the student.

The fourth achievement is a contribution to Instructional Design theory. We applied Instructional Design concepts to develop the extensive Piano Tutor curriculum. We found Instructional Design to be helpful in providing general principles and guidelines, but we needed much stronger analytic tools to develop the Piano Tutor curriculum. We invented a formal representation for curricula, and we developed computer programs to analyze these curricula for a broad range of properties. This new approach to curriculum design has far-reaching implications for future computer-based instruction systems as well as for textbooks and hypermedia systems. [Capell 93]

The Piano Tutor is closely related to a number of other intelligent tutoring systems [Sleeman 82, Anderson 89], but intelligent tutoring systems rarely incorporate multimedia. Two exceptions are a code inspection system [Stevens 89] and a CPR instruction system [Hon 82]. Only the CPR system teaches a psychomotor skill as does the Piano Tutor. A distinguishing feature of the Piano Tutor is its large number of lessons and its ability to assemble lessons into an individually tailored curriculum. Previous music tutoring systems have found some success in the areas of ear-training and theory, but performance-oriented instruction software has often suffered from inadequate or inflexible interfaces [Hofstetter 88]. Another effort to use score following software with students is the Artificially Intelligent Computer Performer (AICP) at Connecticut College [Zahler 91].

The next section describes the Piano Tutor, and the following sections present in greater detail what we feel are our major achievements. The last section outlines other ‘‘spinoffs’’ of this research.

2. The Piano Tutor

The Piano Tutor teaches beginners to play the piano. It consists of an electronic piano with a computer interface, a computer and monitor, a videodisc player and second monitor, and an audio mixer to combine piano sounds, digitized voice from the computer, and sound from the videodisc.

The Piano Tutor assumes no initial musical knowledge, so the Piano Tutor must teach concepts such as notation, pitch, rhythm, and basic music structure in addition to piano performance skills. The basic approach of the Piano Tutor is to teach in units of short lessons that address one to a few concepts each. A lesson begins with a multimedia presentation to introduce the concept. Then, the Tutor asks the student to perform a task (usually a piece of music) that demonstrates mastery of the new concept. The Piano Tutor monitors the student’s performance and offers suggestions if the student makes mistakes. When the new concept is mastered, the Piano Tutor selects a new lesson and the teaching process continues.

The Piano Tutor is a large project with many components. The greatest value of the project may be its successful integration of these components. In fact, one interesting aspect of the Piano Tutor is how well this complicated engine is hidden ‘‘under the hood’’ of the exterior interface. Nevertheless, we will describe the major components separately in the following sections.

3. The Human-Computer Interface

We set out to make the Piano Tutor emulate human teachers, and this required the development of new interface techniques. We were attracted to the idea that a video could make the system more ‘‘friendly’’ and supportive of students. In addition, we anticipated that students would find it easier to learn the psychomotor skills needed for playing by seeing them demonstrated on the video by a real teacher. One pleasant surprise was that we could augment video with digitally recorded speech. This greatly extended our limited 30 minutes of video and still preserved the human touch we were after. Ultimately, we supplemented our presentations with graphics, computer generated music, and music notation. These helped us to communicate effectively with students.

Another aspect of emulating teachers is that the system must take an active role in teaching. Many educational systems have been little more than active books, and we see this approach repeated in many hypermedia systems that leave navigation up to the student. In contrast, we feel that a primary function of the teacher is to guide the student toward instructional material and exercises. This is a difficult task for computers, but we have developed a number of techniques to support this goal, and we have demonstrated that they work effectively.

A key to the kind of active instruction provided by the Piano Tutor is the ability to analyze student performances. This allows the system to build a model of what the student knows and does not know, and that in turn guides the selection of new material. This analysis process is discussed in greater detail below. In addition, the curriculum must be organized according to some formal principles in order to simplify the search for appropriate lesson materials. This organization is discussed in Section 4. The Piano Tutor has succeeded in demonstrating that intelligent systems can play an active role in guiding students.

Our effort of emulating teachers was given a considerable boost by the prior existence of real-time score-following software. Score following refers to the ability of a computer to track or follow a musical score while it is being performed by a student. The analogy to speech would be following a written text while listening to the spoken version. Score following is an essential step in listening to and understanding a student performance. As in a lesson with a human teacher, it allows the student to set his or her own tempo, leaving enough room to make minor timing or pitch errors without confusing the computer analysis software.

Another function of score following allows for the synchronization of accompaniment. One of the teaching techniques incorporated into the system is to provide accompaniments for the pieces presented in each lesson to enhance the auditory skills of the students, to help them with rhythm, phrasing, and dynamics, and to give them the experience of ensemble playing. Score following also allows us to turn pages of music on the computer screen automatically. Again, this enhances our ability to provide a natural human-computer interface.

4. Instructional Design

Our goal from the start was to design a system that could emulate the student/teacher relationship that exists in a one-on-one music lesson. This meant that we had to create a system capable of adapting to the needs of each student. The problem was not to design a single curriculum, but to build an intelligent system that could design a new curriculum for each student. Therefore, our task was to

- Design a set of component lessons with explicit relationships to one another, so that lessons could be assembled into a curriculum, and
- Develop and automate strategies for assembling a curriculum from component lessons.

We feel the result was a breakthrough in Instructional Design. We developed a formal representation for lessons in which every lesson has a list of prerequisites and objectives. The student's state of knowledge is modeled as a set of skills. When the student masters a new skill, the skill is added to the student's skill set. Consistent with instructional design principles, a student is qualified to take a lesson when the prerequisites of the lesson are all contained in the student's skill set. If the student is successful in taking the lesson (lessons have behaviorally described evaluation criteria), then the objectives of the lesson are considered to be mastered. They are therefore added to the student's acquired set of skills.

The strength of this model lies in the fact that computers can simulate a student's progress through the curriculum. Computers can also analyze the network of lessons to determine whether certain desirable properties exist. For example, every skill should be taught by at least one lesson. Every lesson should teach something the student does not already know. There should be a way, via a sequence of lessons, to learn every skill. With over 100 lessons in the Piano Tutor, these maxims would be extremely difficult to check by hand. We developed techniques whereby computers can check for these and many other useful properties automatically in minutes. When errors are found, it is a relatively simple matter to revise the design since no time has been invested in scripting, media production, or programming. These tasks are performed only after a complete design has been validated by computer.

This formalized approach to curriculum design is not at all limited to the Piano Tutor, nor is it limited to intelligent teaching systems. We have discussed these ideas with other educators at Carnegie Mellon and found these ideas seem to formalize existing ideas of how computers might help teachers. One professor is interested in computer-assisted textbook authoring, and is hoping to apply our ideas. It also seems that hypermedia and hypertext systems, for which effective choices of links are an oft-cited problem [ACM 89], could benefit from the formal approach that we offer.

5. The Expert System

The Piano Tutor is by far the most sophisticated music-teaching computer system known to us. To a great extent, the capabilities of the Piano Tutor are a result of its expert system component, which analyzes student performances and chooses how to proceed. In essence, this is where teaching knowledge is utilized. Some key aspects of the expert system are that it works in close conjunction with our curriculum design, and it operates at two levels: within lessons and outside of lessons.

An important design decision in the Piano Tutor was to factor the curriculum into a global and a local level. At the global level, the problem is to select a lesson from a large set of possibilities. At the local level, the problem is to deliver the lesson, including specific suggestions in response to student performances. We found this two-level structure to work quite well. As noted above, the global level is more or less independent of the subject area, so much of our work here is relevant to other domains. Work at the global level focuses on curriculum design, and by dealing with fairly abstract lessons, we can more easily address curriculum planning issues.

Within lessons, interaction tends to be much more focused. It has been well-known since the beginnings of artificial intelligence research that restricted domains are much easier to deal with than unrestricted ones. In the case of the Piano Tutor, the performance task for the student within a lesson is very specific, so the Piano Tutor can respond with very specific and helpful comments.

One of the liabilities of a two-level scheme is that it may be difficult to notice patterns that span multiple lessons. To solve this problem, we attempt to update the student model with information that might be useful across lessons. For example, if a student has problems with rhythm, a corresponding skill might be decremented by a lesson to indicate that a potential problem exists. If several lessons do this, the cumulative effect will be to communicate to the expert system that more work is needed on rhythm.

6. Results

We conducted a pilot study using students, staff, and faculty from the Carnegie Mellon community. The purpose of this study was not to perform a controlled objective experiment which would require a large student population and very careful design. Instead, we hoped to characterize the Piano Tutor as an instructional system: do students like using the system?, do they learn from it?, are aspects of the system confusing?, are there components missing?, do students need human assistance?, and so on.

We started with just a few students and built up to a total of eighteen (18). Ten (10) students completed the Piano Tutor curriculum, and eight (8) withdrew, mostly for reasons of personal schedules such as academic pressures.

We have collected data in several ways. The Piano Tutor automatically keeps a log of each student, so we know what lessons were taken and how much time was spent on each. We also asked students to fill out an evaluation form after their initial exposure to the Piano Tutor. Finally, we have tested students with standard piano instruction material to see if the knowledge and skills learned through the Piano Tutor are transferable to current curricula.

The logs support our hypothesis that a system could automatically tailor a curriculum to the needs of each student. Of the 10 students completing the curriculum, the time-to-completion ranged from 17 calendar days to 159 days, and from 3.7 on-line hours to 21 hours. These figures show that quick students or students with some background are not held back by a rigid or inappropriate curriculum. One might argue that the quick students simply play everything correct on the first try and therefore take less time. However, our logs also show that the system gave more lessons to the slower students. For example, the number of presented music performance lessons ranges from 36 to 53. Clearly, the Piano Tutor is varying the lesson content according to the ability of the student.

Our evaluation forms are more subjective but perhaps more useful. We received a number of constructive comments that can be applied to future systems. Overall, the forms are very positive. Here are some responses to the questions, ‘‘Do you enjoy working with the Piano Tutor? Are you learning what you want to learn?’’

- ‘‘Yes! Yes!’’
- ‘‘I appreciate the self-paced aspect and the fact that a computer is judging my progress rather than a person.’’
- ‘‘Yes. I had never learned Bass Clef before.’’
- ‘‘Very much! [and to the second question:] Not sure. It is teaching me to play the piano. (But the true judge would be a human teacher.)’’
- ‘‘I enjoyed it very much but I’d like to learn more.’’
- ‘‘I think it is fun working with the Tutor. The hardest thing for me is to learn how to keep time. The Tutor gets me on that all the time. So, yes, I am learning what I want and *need* to learn.’’

Our survey shows that students enjoy the style of teaching embodied in the Piano Tutor and they feel it is a good way to learn.

Every student spent a small amount of time with human teachers to assess their progress and supplement the Piano Tutor by checking on posture, ease of movement, and other physical components of piano playing. In general, we found students were learning rapidly, and they were able to apply their knowledge and skills in sight-reading tasks outside the Piano Tutor curriculum. One of the surprises was that students seem to have better than average ability to keep time and play in rhythm. We believe the constant feedback from the Piano Tutor promotes good practice habits, as illustrated by the last student comment listed above.

In summary, we set out to evaluate the Piano Tutor by testing it with a small pool of students. As expected, we found many small problems and we fixed many of them by augmenting the curriculum when it was found lacking. Overall, though, the testing went very smoothly. We found no serious problems with our approach, and we were gratified that students were so positive about the system. To a great extent, the numbers speak for themselves: most of our students stayed with the system to the end. Those that finished mastered what would normally be considered at least a one-year curriculum. The *average* time was 69 calendar days and less than 20 on-line hours.

7. The Future

There are now only two operational Piano Tutor systems. We intend to keep these systems functional on the Carnegie Mellon campus for the foreseeable future, and we welcome visitors to try the system for themselves. We expect the mere existence of these systems will inspire and inform a great deal of future work in music education and intelligent tutoring. We are hopeful that a commercial version of the Piano Tutor will make these ideas even more available.

Meanwhile, the organization of the Piano Tutor seems applicable to other domains. We are working toward a framework for general intelligent multimedia instruction based on the system architecture that we created for the Piano Tutor.

8. Conclusion

The Piano Tutor Project established a new plateau of excellence in computer-based music instruction. Having received world-wide recognition, we feel confident that we have had an impact on the designers of future educational systems. The main contributions of the Piano Tutor include the ideas of active, intelligent, multimedia instruction, and formal support for curriculum design.

9. Acknowledgments

We are extremely indebted to the Markle Foundation for support, which made all of this possible. The Piano Tutor project began in the Center for Art and Technology in the College of Fine Arts, Carnegie Mellon University. The Center is now the Studio for Creative Inquiry.

References

[ACM 89] ACM. *Hypertext '89 Proceedings*. ACM, 1989.

[Anderson 89] Anderson, J. R., F. G. Conrad, and A. T. Corbett. Skill acquisition and the LISP TUTOR. *Cognitive Science* 13(4):467-505, Oct-Dec, 1989.

[Blattner 92] Blattner, M. M. and R. B. Dannenberg (editors). *Multimedia Interface Design*. ACM Press, 1992.

[Bloch 85] Bloch, J. J. and R. B. Dannenberg. Real-Time Computer Accompaniment of Keyboard Performances. In B. Truax (editor), *Proceedings of the International Computer Music Conference 1985*, pages 279-290. International Computer Music Association, 1985.

[Capell 93] Capell, P. and R. B. Dannenberg. Instructional Design and Intelligent Tutoring: Theory and the Precision of Design. *Journal of Artificial Intelligence in Education* 4(1):95-121, 1993.

[Dannenberg 88] Dannenberg, R. B. and H. Mukaino. New Techniques for Enhanced Quality of Computer Accompaniment. In C. Lischka and J. Fritsch (editor), *Proceedings of the 14th International Computer Music Conference*, pages 243-249. International Computer Music Association, San Francisco, 1988.

[Dannenberg 90a] Dannenberg, R. B., M. Sanchez, A. Joseph, P. Capell, R. Joseph, and R. Saul. A Computer-Based Multi-Media Tutor for Beginning Piano Students. *Interface* 19(2-3):155-73, 1990.

[Dannenberg 90b] Dannenberg, R. B. An Expert System for Teaching Piano to Novices. In S. Arnold and G. Hair (editor), *ICMC Glasgow 1990 Proceedings*, pages 20-23. International Computer Music Association, San Francisco, 1990.

[Dannenberg 92] Dannenberg, R. B. and R. L. Joseph. Human-Computer Interaction in the Piano Tutor. *Multimedia Interface Design*. In Blattner, M. M. and R. B. Dannenberg, ACM Press, 1992, pages 65-78.

[Hofstetter 88] Hofstetter, F. T. *Computer Literacy for Musicians*. Prentice Hall, Englewood Cliffs, NJ, 1988.

[Hon 82] Hon, D. Interactive Training in Cardiopulmonary Resuscitation. *Byte Magazine* 7(6), June, 1982.

[Sleeman 82] Sleeman, D. and J. S. Brown (eds.). *Intelligent Tutoring Systems*. Academic Press, New York, 1982.

[Stevens 89] Stevens, S. M. Intelligent Interactive Video Simulation of a Code Inspection. *Communications of the ACM* 32(7):832-43, July, 1989.

[Wenger 87] Wenger, E. *Artificial Intelligence and Tutoring Systems*. Morgan Kaufmann Publishers, Inc., 1987.

[Zahler 91] Zahler, N. CEDS TO GROW A CAT: A Progress/Studio Report. In B. Alphonce and B. Pennycook (editor), *ICMC Montreal 1991 Proceedings*, pages 455-458. International Computer Music Association, 1991.

International Journal of Artificial Intelligence in Education (1997), 8,30-43

Intelligent Tutoring Goes To School in the Big City

Kenneth R. Koedinger
Human-Computer Interaction Institute
School of Computer Science
Carnegie Mellon University
Pittsburgh, PA 15213
USA
ken.koedinger@cs.cmu.edu
http://sands.psy.cmu.edu/ACT/people/koedinger.html

John R. Anderson
William H. Hadley
Mary A. Mark
Department of Psychology
Carnegie Mellon University
Pittsburgh, PA 15213
USA

Abstract. This paper reports on a large-scale experiment introducing and evaluating intelligent tutoring in an urban High School setting. Critical to the success of this project has been a client-centered design approach that has matched our client's expertise in curricular objectives and classroom teaching with our expertise in artificial intelligence and cognitive psychology. The Pittsburgh Urban Mathematics Project (PUMP) has produced an algebra curriculum that is centrally focused on mathematical analysis of real world situations and the use of computational tools. We have built an intelligent tutor, called PAT, that supports this curriculum and has been made a regular part of 9th grade Algebra in 3 Pittsburgh schools. In the 1993-94 school year, we evaluated the effect of the PUMP curriculum and PAT tutor use. On average the 470 students in experimental classes outperformed students in comparison classes by 15% on standardized tests and 100% on tests targeting the PUMP objectives. This study provides further evidence that laboratory tutoring systems can be scaled up and made to work, both technically and pedagogically, in real and unforgiving settings like urban high schools.

1. Introduction

We have created an intelligent tutoring system for algebra problem solving that we call PAT. PAT stands for PUMP Algebra Tutor or Practical Algebra Tutor. PAT is practical in two ways. First, PAT is practical in its pedagogical focus. Students engage in investigations of real world problem situations and use modern algebraic tools (spreadsheets, graphers, and symbolic calculators) to express covariance relationships, to solve problems and to communicate results. Second, PAT is practical in going beyond a laboratory prototype to a fully functioning system. It is currently being used by more than 500 high school students in 3 Pittsburgh city schools.

This paper reports on a large-scale experiment in the classroom implementation of PAT. We start with a description of the system design -- a marriage of content guidance, provided by experts in mathematics pedagogy, and scientific support, provided by the ACT theory and cognitive tutoring technology (Anderson, Corbett, Koedinger, & Pelletier, 1995; Anderson & Pelletier, 1991). Next, we present the results of the first formative evaluation of this system. Students in tutor-using classes outperformed students in comparison classes by 15% on standardized tests and 100% on tests that emphasized real world problem solving and multiple mathematical representations.

2. A Curriculum and Cognitive Tutor for Practical Algebra

2.1. Client-Centered Design and the PUMP Curriculum

The PAT tutor has been developed through a collaboration between the Pittsburgh Urban Mathematics Project (PUMP) in the Pittsburgh School System and the cognitive tutoring group at Carnegie Mellon University. Critical to the success of this project has been a client-centered design approach that has matched our client's expertise in curricular objectives and classroom teaching with our expertise in artificial intelligence and cognitive psychology.

As part of the Pittsburgh Urban Mathematics Project (PUMP), local mathematics teachers have produced a more accessible algebra curriculum that focuses on mathematical analysis of real world situations and use of computational tools. The PUMP curriculum materials employ "real world" situations designed to make mathematics more meaningful and accessible to students. All students come to high school with experience of the mathematics used in "everyday" life, but many are unable to connect this to "school" mathematics (Resnick, 1987). The PUMP curriculum materials try to bridge this gap by using situations from everyday life to generate the mathematics and as a means for the students to anchor their knowledge (cf. CTG, 1990). The unifying concept of the PUMP Algebra curriculum is the use of functional models, represented variously in tables, graphs, and symbols, to analyze and explore situations. The PUMP curriculum is consistent with the new curriculum recommendations of the National Council of Teachers of Mathematics (NCTM, 1989). NCTM recommends increased attention to the use of real-world problems, use of computer utilities, mathematical communication, and making connections. They also recommend decreased attention to traditional word problems by type (e.g., coin, work, mixture), the simplification of radicals, factoring polynomials, and other paper-and-pencil techniques.

In the PUMP classroom students work on mini-projects investigating problem situations like comparing the current quantity and growth rate of old growth forest in the US to the harvest rate. Students investigate such situations by (1) addressing questions, like "Assuming these figures do not change, when will all the old growth forest be gone?", (2) creating a table to investigate the relationships between quantities, (3) scaling, graphing and identifying points of intersection, (4) using algebraic notation to concisely represent the underlying structure of the situation, and (5) using algebraic notation to compute solutions.

PAT was built to support this kind of mathematical investigation and problem solving. Most importantly, PAT was designed to help students develop algebraic skills which they can use in the context of real-life problem situations. The PAT learning environment includes a set of computational tools to aid investigation (a spreadsheet, grapher, and symbolic calculator) and an organized curriculum of problem situations. In developing PAT, we worked closely with both curriculum designers from the school system, and teachers in actual classrooms with actual students, all of whom have given us valuable information. Direct observation and protocols from tutoring sessions provide rich sources of evidence that we have drawn on to increase our understanding of students and to improve the design of PAT.

2.2. Principled Design of Cognitive Tutors

The design of PAT was also guided by theoretical principles. As a *cognitive tutor* (Anderson, et. al, 1995), PAT has the defining feature of containing a psychological model of the cognitive processes behind successful and near-successful student performance. Based on the ACT theory, this cognitive model is written as a system of if-then production rules that are capable of generating the multitude of solution steps and mis-steps typical of students. The cognitive model is the basis for two student modeling techniques: model tracing and knowledge tracing. *Model tracing* is used to monitor student's progress through a problem solution (see Anderson, Boyle, Corbett, & Lewis, 1990). This tracing is done in the background by matching student actions to those the model might generate. The tutor is mostly silent. However, when help is needed, the tutor knows where the student is and can provide hints that are individualized to the student's particular approach to the problem. *Knowledge tracing* is used to monitor students' learning from problem to problem (see Corbett & Anderson, 1992). A Bayesian estimation procedure identifies students' strengths and weaknesses relative to the production rules in the cognitive model. This assessment information is used to individualize problem selection and optimally pace students through the curriculum.

PAT's cognitive model and general design is the consequence of basic research on mathematical cognition. Our previous research has shown that students have informal *inductive* routes to mathematical knowledge that often precede formal instruction in the deductive use of symbols (Koedinger & Anderson, 1990; 1991). Thus, contrary to popular belief, students can perform better on algebra word problems under certain circumstances than on the equivalent algebraic equations (Koedinger & Tabachneck, 1995). We applied such results in early experiments with PAT where we showed that students learned more from a theory-inspired "inductive-support" version of the tutor than from a "textbook" version based on a popular Algebra text (Koedinger & Anderson, 1996).

2.3. Description of PAT: A Cognitive Tutor for Practical Algebra

In day to day life, people deal with a wide variety of situations that cause them to draw on basic algebra and reasoning skills. Checking the amount of a paycheck, estimating the cost of a rental car for a trip, and choosing between long-distance telephone service offers from AT&T and MCI are just three examples of real-world situations in which algebraic skills are useful. As part of the development of PAT, Pittsburgh teachers wrote problem situations like these intended to be personally or culturally relevant to students. Some problem situations are of potential general interest (e.g., the decline of the condor population), while others are more specific to Pittsburgh 9th graders (e.g., making money shoveling snow). These problems were added to PAT using a problem authoring environment in which teachers type the problem description, enter an example solution, and edit the guesses the system makes about how quantities in the solution to relate to phrases in the text.

Students work through PAT problem situations by reading a textual description of the situation and a number of questions about it. They investigate the situation by representing it in tables, graphs, and symbols and using these representations to answer the questions. Helping students to understand and use multiple representations of information is a major focus of the tutor.

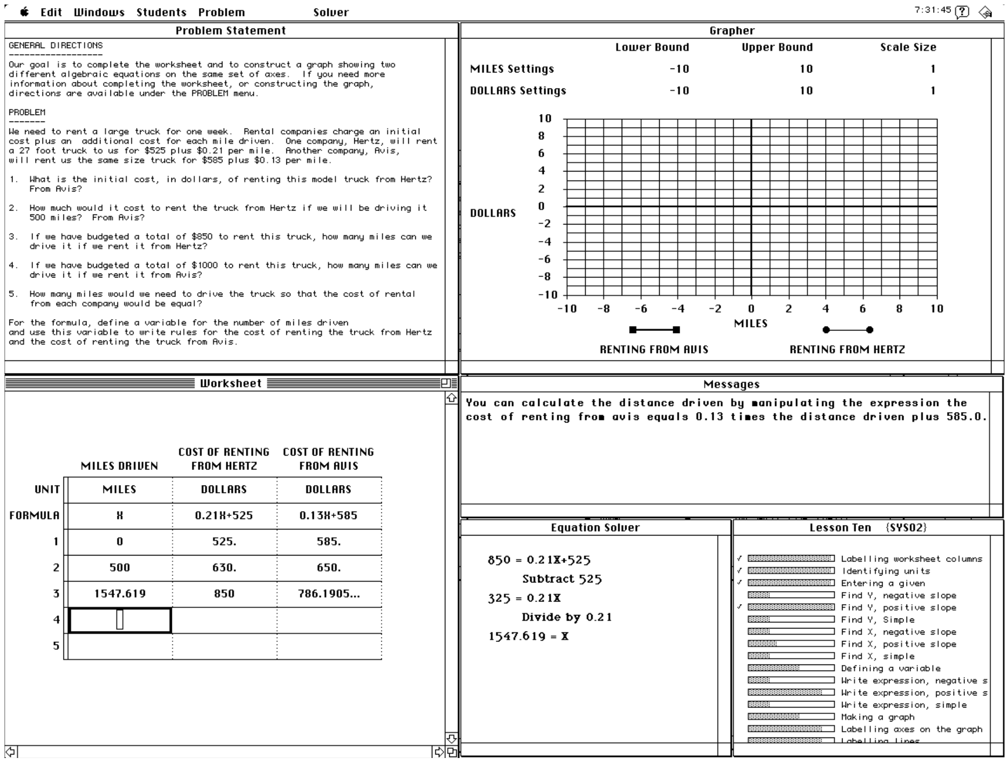


Figure 1. A screen from PAT, a cognitive tutor for practical algebra.

In Figure 1, the PAT screen shows a student's partial solution for a problem. This problem appears in later stages of the curriculum after students have acquired some expertise with constructing and using graphs and tables for single linear equations. The top-left corner of the tutor screen provides a description of the problem situation. The problem involves two rental companies, Hertz and Avis, that charge different rates for renting large trucks. Students investigate the problem situation using multiple representations and computer-based tools, including a spreadsheet, grapher, and symbolic calculator -- in Figure 1 these are the Worksheet, Grapher and Equation Solver windows, respectively. Students construct the Worksheet (lower-left of Figure 1) by identifying the relevant quantities in the situation, labeling the columns, entering the appropriate units, entering algebraic expressions, and by answering the numbered questions in the problem description. Students construct the graph of the problem situation (upper-right) by labeling axes, setting appropriate bounds and scale, graphing the lines, and identifying the point of intersection. The Equation Solver (lower-center) can be used at any time to help fill in the spreadsheet and identify points of intersection. The student can use these representations to reason about real-world concerns, such as deciding when it becomes better to rent from one company rather than another.

Most students spend 20-30 minutes solving a problem of this type on the computer. During that time, the tutor monitors their activities, and provides feedback on what they are doing. The provision of timely feedback is one way in which the tutor individualizes instruction. For the most part, the tutor is silently tracing students actions in the background. When a student makes an error, it is "flagged". For text items, flagging is achieved by putting the student's entry in **outline text**. Errors in plotting points in the grapher tool are flagged by coloring the point gray rather than black and indicating the coordinates of the incorrectly placed point so that the student can see how they differ from the intended coordinates in a Worksheet row. Often flagging is done without comment, which appears to reduce students' negative feelings associated with making errors in math class. But if the student's error is a commonly occurring slip or misconception that has been codified in a buggy production rule, a message is provided that indicates what is wrong with the answer or suggests a better alternative. Examples of buggy productions in PAT include putting a correct value for a cell in the Worksheet in an adjacent row or column, confusing the dependent and independent variable in formula writing, incorrectly entering arithmetic signs in equation solving, and confusing the x and y coordinates in graphing.

This provision of timely feedback is a critical feature of cognitive tutors that leads to substantial cognitive and motivational benefits. In a parametric study with the LISP tutor, Corbett and Anderson (1991) provided a demonstration of how the immediacy of feedback leads to dramatic reductions in the learning time needed to reach the same level of post-training performance -- learning time was 3 times longer in the most delayed feedback condition than in the most immediate. In addition to cognitive benefits, there are also motivational benefits of timely feedback. Much like the motivational attraction of video games, students know right away that they are making progress and having success at a challenging task. Further, because the system does not make a big deal out of errors, students do not feel the social stigma associated with making an error in class or on homework. Errors are a private event that are usually quickly resolved and the student is then back to making progress.

In addition to error feedback, a second way PAT individualizes instruction is by giving help on request. At any step in constructing a solution, a student can ask for help. The tutor chooses help messages for presentation by using the production system to identify a desirable next activity. Choice of a desirable action is based on the student's current focus of activity, the overall status of the student's solution, and internal knowledge of interdependencies between problem-solving activities as represented in the production rules. Multiple levels of help are provided so that more detailed information can be obtained by making repeated help requests.

The "Message" window in Figure 1 shows the result of a student help request. The current focus of attention is based on the selection of the worksheet cell for question 4, under the column entry for 'miles driven' -- this cell is highlighted in Figure 1. Given the information in the problem about the costs of renting from Avis or Hertz, the student is asked: "If we have budgeted a total of $1000 to rent this truck, how many miles can we drive it if we rent it from Hertz?"

An initial hint directs the student to consider information in the question that is relevant to finding a value for the distance: "You know that the cost of renting from Avis depends on the distance driven, and you are given a value for the cost of renting from Avis." By asking for help a second time, the student receives a more detailed description suggesting that the distance can be calculated by relating information given in the question to a particular algebraic relationship described in the problem. "You can calculate the distance driven by manipulating the expression the cost of renting from Avis equals 0.13 times the distance driven plus 585.0." Further messages are also available, describing in more detail the type of equation that the student needs to set up and solve. The Equation Solver window (lower-center) shows how the student solved a similar question (question 3). The student enters their own equation and solves it by indicating standard algebraic manipulations.

By keeping students engaged in successful problem solving, PAT's feedback and hint messages reduce student frustration and provide for a valuable sense of accomplishment. In addition to these functions of model tracing, PAT provides learning support through *knowledge tracing*. Results of knowledge tracing are shown to student and teacher in the Skillometer window. By monitoring a student's acquisition of problem solving skills through knowledge tracing, the tutor can identify individual areas of difficulty (Corbett, Anderson, Carver, and Brancolini, 1994) and present problems targeting specific skills which the student has not yet mastered. For example, a student who was skilled in writing equations with positive slopes and intercepts, but had difficulty with negative slope equations would be assigned problems involving negative slopes.

Knowledge tracing can also be used for "self-pacing", that is, the promotion of students through lessons of the curriculum based on their mastery of the skills in that lesson. In the 1993-94 study, knowledge-tracing capabilities of the tutor were not fully used. Knowledge tracing controlled the selection of problems within lessons, but not the self-paced advancement of students between lessons.

Self-pacing was not used for two reasons. First, participating teachers were not certain how to coordinate students' differing rates of progress through PAT lessons with the material being addressed in the regular classroom. Teachers were already tackling a number of new challenges in using PAT and in simply using computers in classroom. Second, the researchers needed more student data to decompose domain competence into production rules that best match the grain size of algebra learning events.

Instead of self-pacing progress between lessons, students spent a fixed amount of time on each lesson, about 3-4 class periods. At the end of each such installment, all students were advanced to the next lesson whether or not knowledge tracing how judged them to have mastered the skills in that lesson. The current 1994-95 study fully utilizes knowledge-tracing capabilities of the tutor, within and between lessons.

The PAT curriculum for the 1993-94 school year contained six lessons of problems. Initially, students explored common situations involving positive quantities and graphing in the first quadrant of the Cartesian coordinate system (positive values only on the x and y axis's). As the year progressed more complex situations were analyzed that required negative quantities and graphing in the other quadrants. Similarly, as the situations increased in complexity, formal equation solving and graphing techniques were introduced to enable students to find solutions. Systems of linear situations and quadratics are developed through the introduction of situations in which they naturally occur. For example, two rival companies that make custom T-shirts with different price structures provided an opportunity to explore a system of two linear equations. Modeling vertical motion provided a context for introducing and using quadratic functions. Problems involving quadratic functions are part of the PUMP curriculum, but were not yet implemented in PAT.

2.4. Special Features of the PUMP Classroom

In the classroom students work together in groups or teams to solve problems similar to those presented by the tutor. Teams construct their solutions by making tables, expressions, equations, and graphs which they then use to answer questions and make interpretations and predictions. The transfer of the computer tools to paper and pencil techniques and the interpretation and understanding of these tools are the emphasis of the classroom. Literacy is stressed by requiring students to answer all questions in complete sentences, to write reports and to give presentations of their findings to their peers.

The project also uses alternate forms of assessment including performance tasks, long term projects, student portfolios, and journal writing. From the first day all answers must be written in complete sentences to be accepted. At the end of each quarter students are given a performance task as a final examination. At the end of each semester these tasks are graded by the teachers at a mini-scoring conference where all the teachers in the project come together, construct a scoring rubric, and score all the student papers in an afternoon. Because each teacher scores papers from every other teachers' class as well as their own they come to have a better understanding of the objectives of this new curriculum.

3. A Large-Scale Classroom Experiment

The on-going evaluation of PAT and the PUMP curriculum is a kind of "design experiment" (Brown, 1992) on the effect of both instructional innovations in the unforgiving setting of real schools. Evolving versions of PAT have been tested in laboratory experiments following the cognitive tutoring design methodology (Koedinger & Anderson, 1996; Anderson, et al., 1995). However, the urban classroom situation is unlike the refined and controlled environment of the lab and laboratory standards cannot realistically be applied. As such, we have begun by addressing the practical question of whether the whole package, PUMP curriculum and PAT, is effective by comparing it against a traditional curriculum without PAT. By laboratory standards, this experiment is confounds two variables, a change in curriculum and the use of PAT. However, our strategy is first to establish the success of the whole package and then, if indeed it is successful, to examine the effect of the curriculum and intelligent tutoring components independently.

3.1. Method

Data reported is from the 1993-94 school year. The student population came from 3 Pittsburgh Public High Schools, Langley, Brashear and Carrick, with similar demographics and student aptitudes. These schools are about 50% African-American, 50% single-parent families, and only 15% go on to college. Students in the experimental classes received two treatments: they were taught the new PUMP curriculum and they worked with PAT for approximately 25 out of 180 of their normal class periods. Students worked on 6 lessons with the complete PAT environment and 1 lesson with the equation solving tutor module alone. The "PUMP+PAT" group consisted of 20 algebra classes that involved 470 students and 10 teachers. The 12 classes from Langley high school contained students who in prior years would have been placed into a non-academic general math class, rather than algebra. Because of satisfaction with the pilot use of the curriculum and tutor in the prior year, Langley decided to assign all 9th graders to algebra instead.

The comparison classes received a traditional curriculum and did not use PAT. There were two types of comparison classes. The matched "Comparison" group consisted of 5 algebra classes that involved 120 students and 3 teachers. These students were from roughly the same background as the experimental classes. If anything, Comparison students were somewhat better prepared as a group given the inclusion of students in the Langley experimental classes who would otherwise have been placed in a lower level math. The "Scholars-Comparison" group consisted of 2 "scholars" algebra classes involving 35 students and 1 teacher. Scholars courses are an academic track for students who are selected based on prior school success. None of the experimental classes were scholars algebra classes.

We looked at students' math grades in the previous school year to verify that there were no differences in students prior mathematical background that would put the PUMP+PAT group at an advantage. Using 1 for a D and a 4 for an A, the grade averages were lowest at 2.1 for PUMP+PAT, next at 2.4 for the Comparison group, and highest at 2.6 for the Scholars-Comparison group.

3.2. Assessment Design

Designing a fair assessment plan for an experiment involving curriculum reform is difficult. Standardized tests are often rejected for this purpose because they do not address the objectives of the new curriculum. However, we reasoned that if PUMP+PAT students did better on reform objectives yet were worse on the basic skills tapped by standardized assessments, we would have just shifted the focus of instruction. Such assessments would in effect reflect creation of a new course: not necessarily a bad goal, but not evidence of an improvement in the instructional process. We wanted to show experimental classes doing much better on the reform objectives of authentic problem solving and representational tool use, and at least as well or better on the basic skills tapped by standardized tests. Thus, we gave both types of tests.

We used two types of standardized tests: an Iowa Algebra Aptitude test and a subset of the Math SAT appropriate for 9th graders. We also designed two tests to assess reform objectives reflecting NCTM's recommendations and the PUMP curriculum. The Problem Situation Test was created to assess students' abilities to investigate problem situations, presented verbally, that have algebraic content. The Representations Test was created to assess students' abilities to translate between representations of algebraic content including verbal descriptions, graphs, and symbolic equations.

The assessments were given over two days at the end of the spring semester during a normal 44 minute class period. All students took the Iowa on the first day of testing. On the second day, approximately half of the students took each of the other tests.

3.3. Results and Discussion

Table 1 shows the percentage correct, standard deviation (in parentheses), and N (second line) for the groups on the four tests. Note that because of the high absenteeism that is typical of city schools particularly near the end of the school year, there were a substantial number of students who missed one or both days of the assessment. For each test, a between-subjects ANOVA was run with three levels, Comparison, PUMP+PAT, and Scholars-Comparison. The addition of the Scholars-Control group provides a upper edge comparison for the intervention. The results of these tests are shown in the 5th column of Table 1.

The 6th and final column shows effect sizes in terms of standard deviation units (sigma) of the PUMP+PAT group above the Comparison group. Effect sizes provide a metric for assessing the impact of instructional interventions. The Bloom (1984) result that individual human tutors can bring students 2 sigma above normal classroom instruction sets a standard of comparison for the impact of intelligent tutors. Previous studies have shown cognitive tutors to yield as much as a 1 sigma effect over control conditions (Anderson, Corbett, Koedinger, and Pelletier, 1995; Koedinger & Anderson, 1993).

Table 1. Results of Final Testing of PUMP+PAT, Comparison, and Scholars-Comparison Classes

	Comparison	PUMP+ PAT	Scholars-Comparison	F value and significance	sigma
Iowa Algebra Aptitude	.46 (.17) 80	.52 (.19) 287	.68 (.17) 34	$F(2,398) = 17.0$ $p < .0001$	0.3
Math SAT Subset	.27 (.14) 44	.32 (.16) 149	.42 (.15) 15	$F(2, 205) = 5.1$ $p < .01$	0.3
Problem Situation Test	.22 (.22) 42	.39 (.33) 127	.38 (.26) 20	$F(2, 186) = 5.3$ $p < .01$	0.7
Representations Test	.15 (.18) 44	.37 (.32) 124	.12 (.16) 18	$F(2, 183) = 13.4$ $p < .0001$	1.2

On the Iowa Algebra Aptitude test, PUMP+PAT scores are significantly higher than the Comparison ($p < .05$), a 0.3 sigma effect. They are significantly lower than the Scholars-Comparison ($p < .01$). On the SAT subset, the PUMP+PAT scores are higher than the Comparison scores (0.3 sigma), but there is a lot of variance in this smaller sample and PUMP+PAT is not significantly higher than Comparison ($p > .05$) nor significantly lower than Scholars-Comparison ($p > .05$). The largest effects come on the new NCTM-oriented tests. On the Problem Situation test, PUMP+PAT scores are significantly and substantially higher than Comparison ($p < .01$), a 0.7 sigma effect. They match up with the Scholars-Comparison ($p > .05$). On the Representations test, PUMP+PAT scores are significantly and substantially higher than Comparison ($p < .01$), a 1.2 sigma effect, and than the Scholars-Comparison ($p < .01$).

To summarize, the PUMP+PAT classes scored about 1 sigma better on the NCTM-oriented tests that were the target of the curriculum. Their scores were about 100% better or double those of the Comparison classes. These learning gains appear to occur at no expense to basic skills objectives of standardized tests. In fact, PUMP+PAT classes scored about 15% better on these tests.

4. Conclusion

Cooperation between the Pittsburgh Urban Mathematics Project and the cognitive tutoring group at Carnegie Mellon has led to the development of the PAT tutor, and its integration into classrooms in three Pittsburgh Public Schools. As expected from past experience (Schofield, Evans-Rhodes, & Huber, 1990; Wertheimer, 1990), the tutor has been enthusiastically received by students and teachers. Teachers comment that working in the computer lab with PAT engages students who present difficulties in the normal classroom. In addition, teachers like the way that the tutor accommodates a large proportion of student questions and frees teachers to give more individualized help to students with particular needs. As one concrete example of teacher support, a teacher's enthusiastic testimonial of the program was critical in convincing the Pittsburgh school board to purchase computer labs to expand the program to two more high schools for the 1994-95 school year.

Evaluation of PAT and the PUMP curriculum is continuing. In the 1994-95 school year, the PAT curriculum expanded to include 10 lessons and 214 problem situations. Students are in the computer lab two days a week, working with PAT at a self-paced rate. Student time on the tutor will more than double (roughly from 25 to 70 days) compared to the 93-94 school year.

Acknowledgments

This research was supported by contract MDR-92-53161 from the National Science Foundation.

Thanks to the teachers of the experimental and comparison classes. Thanks also to other key members of our Pittsburgh Advanced Cognitive Tutor center: Al Corbett, Ray Pelletier, Steve Ritter, Jackie Snyder.

References

Anderson, J. R., Boyle, C. F., Corbett, A. T., & Lewis, M.W. (1990). Cognitive modeling and intelligent tutoring. *Artificial Intelligence*, *42*, 7-49.

Anderson, J. R., Corbett, A. T., Koedinger, K. R., & Pelletier, R. (1995). Cognitive tutors: Lessons learned. *The Journal of the Learning Sciences, 4* (2) 167-207.

Anderson, J. R., & Pelletier, R. (1991). A development system for model–tracing tutors. In *Proceedings of the International Conference of the Learning Sciences* (pp. 1–8). Evanston, IL.

Bloom, B. S. (1984). The 2 sigma problem: The search for methods of group instruction as effective as one-to-one tutoring. *Educational Researcher*, *13*, 3-16.

Brown, A. L. (1992). Design experiments: Theoretical and methodological challenges in creating complex interventions. *The Journal of the Learning Sciences, 2*, 137-178.

Corbett, A.T. & Anderson, J.R. (1991). Feedback control and learning to program with the CMU LISP tutor. Paper presented at the annual meeting of the American Educational Research Association, Chicago, IL.

Corbett, A.T. & Anderson, J.R. (1992). Student modeling and mastery learning in a computer-based programming tutor. In *Proceedings of the Second International Conference on Intelligent Tutoring Systems*. Montreal, Canada.

Corbett, A.T., Anderson, J.R., Carver, V.H. and Brancolini, S.A. (1994). Individual differences and predictive validity in student modeling. In A. Ram & K. Eiselt (eds.) *The Proceedings of the Sixteenth Annual Conference of the Cognitive Science Society*. Hillsdale, NJ: Lawrence Erlbaum.

Cognition and Technology Group at Vanderbilt (1990). Anchored instruction and its relationship to situated cognition. *Educational Researcher, 19* (6), 2-10.

Koedinger, K. R., & Anderson, J. R. (1990). Abstract planning and perceptual chunks: Elements of expertise in geometry. *Cognitive Science*, *14*, 511-550.

Koedinger, K. R., & Anderson, J. R. (1991). Interaction of deductive and inductive reasoning strategies in geometry novices. In *Proceedings of the Thirteenth Annual Conference of the Cognitive Science Society*, Hillsdale, NJ: Erlbaum.

Koedinger, K. R. & Anderson, J. R. (1993). Effective use of intelligent software in high school math classrooms. In *Proceedings of the World Conference on Artificial Intelligence in Education,* (pp. 241-248). Charlottesville, VA: Association for the Advancement of Computing in Education.

Koedinger, K. R., & Anderson, J. R. (1996). Illustrating principled design: The early evolution of a cognitive tutor for algebra symbolization. Submitted to *Interactive Learning Environments*.

Koedinger, K.R., & Tabachneck, H.J.M. (1995). Verbal reasoning as a critical component in early algebra. Paper presented at the annual meeting of the American Educational Research Association, San Francisco, CA.

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

Resnick, L. B. (1987). Learning in school and out. *Educational Researcher, 16*(9), 13-20.

Schofield, J. W., Evans-Rhodes, D., & Huber, B. R. (1990). Artificial intelligence in the classroom: The impact of a computer-based tutor on teachers and students. *Social Science Computer Review*, *8:1*, 24-41.

Wertheimer, R. (1990). The geometry proof tutor: An "intelligent" computer-based tutor in the classroom. *Mathematics Teacher*, April, 308-317

5 Myths about Mastery-Based Learning

Whether or not you've heard the term "mastery-based learning," you've probably encountered it in practice, in school or on the job. In any situation where you're given a set of labs, problems, or activities where your progression is dependent on successful completion of various tasks rather than seat time, you're engaging in mastery-based learning–a teaching method premised on the idea that student progression through a course should be dependent on proficiency as opposed to amount of time spent on academic work.

As every teacher knows, classroom management is a consummate juggling act. To remain attentive to the needs of all students, teachers must engage the more advanced students while helping the struggling ones catch up. At any given point in a lesson, a teacher must decide whether to move through the material aggressively and add more challenges and twists to the problems presented, or build in more of cushion for those who are confused. Any one of these strategies is bound to leave some students feeling bored or confused. Mastery-based learning aims to help teachers in this respect by allowing students to move through coursework at their own pace.

Key features of mastery-based learning (MBL):

1. Curriculum design hinges on assessments
2. Assessments may take any form as long as they determine proficiency
3. Graduation to the next grade/level/topic is contingent upon successful completion of prerequisite assessment.
4. Curriculum is committed to the success of all students; students are not "allowed" to give up.

It turns out that there are quite a few misconceptions about mastery-based learning.

Given new technology that can help us reimagine mastery-based learning, it's prime time to debunk these myths.

Myth 1: Mastery-based learning is difficult to implement.

Mastery-based learning was first introduced in the 1920s through the Winnetka Plan, an educational experiment engineered by district superintendent Carleton Washburne of Winnetka, Illinois. The experiment was inspired by John Dewey's research in the University of Chicago Laboratory School and designed to expand the focus of education to include creativity and emotional and social development. Under early implementations of mastery-based learning, a teacher could provide students with the same labs, quizzes, and tests (through which they could move at their own pace by demonstrating proficiency and having the work checked off) but the teacher still had to evaluate assessments and coach students individually on top of delivering lectures that transmitted the knowledge in the first place.

While the plan received widespread attention, efforts to promote mastery-based learning stagnated after a few decades, given the absence of a technology to help implement it. During this period, it was difficult to conceive of how students might move forward at their own pace and still function within the existing structures of school (classrooms, grades defined by age, rigidly defined schedules) which had evolved by mid-20th century America to seem fairly incontrovertible. Mastery-based learning also created some administrative burden for teachers who had to track students through their self-paced courses and offer remediation when necessary.

New technology allows us to re-envision mastery-based learning, so that it is far more flexible. By breaking up course materials into units of learning objectives and chunking those objectives into digestible modules, educators have developed self-paced courses of study that fit neatly in the most rigid schedules. Computerized adaptive systems bring this modularity to a new level, making the resulting courses both easier to implement and more effective for students. Because academic concepts can now be tagged at the atomic level, it is possible to conceive of corresponding academic work and assessments in smaller and smaller components. Since a computerized system can capture performance and activity on these components, it is possible to offer courses that adapt to student needs on the most precise level. This reduces the work load for teachers who, in previous versions of mastery-based learning, had to coach students individually through their respective courses of study.

Myth 2: Mastery-based learning is expensive.

In the past, MBL has been used in some districts to justify increased funding, increased testing requirements, and a great deal of energy investment from students, parents, and teachers. This does not mean that mastery-based learning is inherently expensive, however. If implemented through online adaptive technology (as described above), mastery-based learning can be introduced at minimal cost.

Mastery-based learning can also provide a fairly inexpensive solution to a number of challenges facing administrators–including the acceptance of an increased diversity of students and the expansion of curriculum knowledge for teachers to cover. Because an adaptive system responds to the exact needs of each individual, it can be used for a wide range of students. And because such a system is computerized and involves a precise tagging system, it is easy to organize large amounts of content and track performance on that content.

Myth 3: Mastery-based learning makes grading and reporting more difficult.

Because MBL requires that students be judged on their mastery of material in an absolute sense as opposed to their performance relative to others, proper reporting requires attention to a whole series of outcomes. In traditional schooling, students typically receive an “A” or a “B” as a grade that summarizes their achievements relative to others (while an “A” may always mean an “A” in some minds, it typically reflects a student’s performance in relation to the rest of the class he or she happens to be in). If MBL is strictly implemented, however, one must report that a student mastered “verbs,” “tenses,” and “parallel sentence structure” but not “idioms” instead of just issuing a “B.” This is understandably more difficult to report and reflect in a transcript.

Adaptive technology provides a ready solution. With a comprehensive dashboard served by an adaptive system, student outcomes can be aggregated and teachers can view all the concepts and skills a student has mastered in a single glance. Trends and patterns of mastery across the class (and even across a grade or district) also become apparent.

Myth 4: In mastery-based learning, too many students will fail (because standards are too high).

As described above, mastery-based learning is premised on the fact that no one is allowed to fail and that everyone (regardless of gender, race, or socioeconomic status) will succeed, given the right conditions. The emphasis on mastery or proficiency as opposed to effort and seat time, however, makes some nervous and raises some questions: what about those who do not pass, who do not demonstrate mastery? And who try and fail repeatedly?

Although it is true that MBL holds all students to the same high standards, the teaching method creates an environment that helps students meet those standards. Anyone who has ever struggled in a classroom knows that missing an insight everyone else experiences can be stressful. Feeling left out or slow in a public situation can indeed exacerbate the challenge, but the self-paced nature of a mastery-based approach allows students who are self-conscious to relax into their learning and make significant gains in a seamless and natural way.

As far as remediation is concerned, any mastery-based system can provide a wealth of triage opportunities, if enough quality content is available. And, with the development of adaptive technology, triage opportunities have the potential to be even more sophisticated than before. An adaptive system can determine the exact needs of each student and match him with learning objects and activities that bring him up to speed quickly.

Myth 5: In mastery-based learning, standards are too low and advanced students are not challenged.

In mastery-based learning, advanced students can progress through material at their own pace and remain engaged by pursuing more challenging work. The richer the content within the learning system, the more material a student can explore if he advances at a swifter pace than the others in his cohort. In this sense, the standards for such students are not low at all–they stretch to help each student maximize potential.

Because success is defined on an absolute and individualized basis, students cannot be satisfied with their achievements relative to others; they are encouraged to seek their own course and take responsibility for their own learning. A sophisticated adaptive learning system can take this to a new level. Because an adaptive system is computerized and involves tagged content, it can be hooked up to enormous repositories of expert material that normally lie beyond the realm of school. When appropriate, such a system can direct students to specific articles, studies, reports and books created by experts, for experts. Adding even a slight degree of adaptivity to the sheer amount of digital content available has the power to significantly amplify the learning experiences we are currently familiar with.

For a more detailed treatment of how adaptive learning can expose students to advanced work, check out my blog post, Why Students Don't Like School Part IV.

KRONKOSKY CHARITABLE FOUNDATION

RESEARCH BRIEF

January 2012

ARTS AND EDUCATION

The national movement for Art and Education advocates the need for improved public school programs in the fine arts, which include music, art, theatre, and dance. Supporters of the movement cite the far-reaching benefits available to school-age children who are exposed to various types of artistic expression. In a collaborative statement by the American Association of School Administrators, the National Education Association, and the National School Boards Association, the organizations explicitly proclaim that "every student in the nation should have an education in the arts" (MENC: National Association for Music Education [MENC], 2011). However, due to increasingly stringent academic requirements and numerous budget cuts, students generally receive a very limited education in the arts.

Research Findings

A broad base of research exists to show that an education in various types of art can have positive effects for children. Generally, the goal of teaching art is to supply children with various skills that can be utilized in other aspects of life. Children who express themselves through music, art, theatre, or dance tend to possess better reasoning and academic skills and develop better social skills. "The arts help children develop literacy skills such as reading, writing, speaking, and listening, while encouraging divergent thinking and problem-solving skills, enabling students to think creatively. Current research has shown that arts education can play a critical role in a child's academic and social development. Well-designed and executed arts education leads to overall improved academic performance, builds skills necessary for workplace success, and has a positive influence on the lives of students," (Americans for the Arts, 2009b).Through art, children learn to express themselves in an appropriate manner. They begin to develop a sense of pride in their accomplishments and view school activities more positively. Furthermore, it has been suggested that educating children in fine arts can bridge the performance gap that exists between different socio-economic groups (National Assembly of State Arts Agencies [NASAA], 2006). Numerous studies support these claims, mentioning that disadvantaged students especially benefit from the integration of fine arts education (Education Partnerships, Inc., n.d.).

In 2009, The National Assessment Governing Board released a study presenting the educational progress of U.S. eighth grade students in visual arts and music. The research findings concluded:

- 8% of surveyed schools do not offer music instruction. 14% of schools do not offer visual arts classes.
- 8% of surveyed schools offer music instruction less than once a week. 10% of schools offer visual arts instruction less than once a week.
- 57% of eighth-graders in 2008 attended schools where students received music instruction at least three or four times a week.
- 47% of eighth-graders in 2008 attended schools where students received visual arts instruction at least three or four times a week.

(National Center for Education Statistics, 2009)

Stanford University, in a 12-month research project, documented the academic activity of young individuals who participated in fine arts for at least three to four hours a day, three days a week. These students were:

- 4 times more likely to be recognized for academic achievement
- 3 times more likely to be elected to class office within their schools
- 4 times more likely to participate in a math and science fair
- 3 times more likely to win an award for school attendance
- 4 times more likely to win an award for writing an essay or poem

(Americans for the Arts, 2009a)

Shady Brook School in Bedford, Texas, recorded the effects of integrating fine arts into a school's curriculum. Administrators had recently initiated an ambitious art curriculum, making art the central focus of the learning process. Over five years, the students' academic skills improved in all areas. Test scores increased by:

- 49% in math
- 63% in reading
- 36% in writing

Travis Elementary School in Dallas, Texas demonstrated the many benefits achieved after integrating reading classes with a theatre program. After two years, TAAS test scores increased by

- 71% in reading
- 39% in writing
- 215% in math

(Casanova and Merriam-Gourley, 2001).

An education in the arts not only benefits children in the academic realm, but provides individuals with skills that are useful in the workforce. Individuals who major in music during college are more likely to be accepted to medical school over students who studied biochemistry. Employers recognize that exposure to the arts allows workers to become creative thinkers and use higher order cognitive skills. "Decades of research show a strong and consistent link between high-quality arts education and a wide range of impressive educational outcomes" (President's Committee on the Arts and the Humanities [PCAH], 2011, p.vi). A New York accounting firm, after hiring four MIT graduates with a minor in the arts, commented that the candidates were set "apart from the others in terms of creative thinking, flexibility, and presentation and that the firm is now using the arts minor as a screening criterion" (Casanova and Merriam-Gourley, 2001).

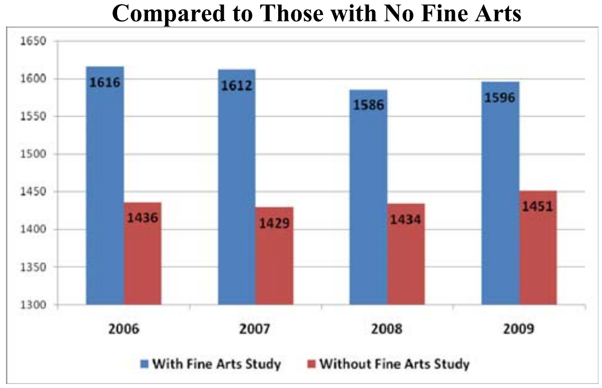
"*Education in the arts is more important than ever. In the global economy, creativity is essential. Today's workers need more than just skills and knowledge to be productive and innovative participants in the workforce. To succeed today and in the future, America's children will need to be inventive, resourceful, and imaginative. The best way to foster that creativity is through arts education."* (PCAH, 2011, p1).

Benefits of an Education in the Arts

Research suggests multiple benefits associated with receiving an education in the arts. In general, skills taught through the arts transmit to other aspects of a student's academic life. Students improve study skills, communication skills, cognitive skills, and learn to act more appropriately during school. This success in school also transfers to success in life. Children learn self-discipline and attentiveness, as well as develop critical emotional, social, and cognitive tools. A fine arts education allows children to express themselves and learn to connect with others (MENC, 2011).

Learning music helps individuals develop skills that are essential in other school subjects. SAT scores provide clear evidence that an education in music improves a student's performance in other academic arenas.

National SAT Scores of Students Enrolled in Fine Arts Compared to Those with No Fine Arts



(Texas Music Educators Association, n.d.b)

Students' SAT scores are correlated to the number of years during which they study music – those who study music longer consistently earn higher scores. According to Americans for the Arts (n.d.), students who took four years of fine arts classes scored 102 points higher on the 2010 SAT (verbal/math sections only) than their counterparts who took one half year or less of fine arts classes.

Students who were ranked as All-State musicians in Texas, consistently scored approximately 20% higher than the national average and about 22% higher than the Texas average on the SAT (Texas Music Educators Association, n.d.a). In Texas, the composite 2010 SAT scores for students ranked as All-State musicians were 390 and 348 points higher than the Texas and national average respectively (Texas Music Educators Association, 2011). Some research indicates that the link between SAT scores and fine arts education is not causation, but simply correlation. Nevertheless, many researchers agree that the unique skills taught in fine arts classes, which are neglected in the instruction of other subjects, help students flourish academically by balancing out the learned tools (Winner & Hetland, 2007). The National Task Force on the Arts and Educations believes that the arts "help students develop skills in group interaction, self-esteem, reflection, decision making and innovative thinking (PCAH, 2011, p5).

Elliot Eisner (n.d.) lists ten lessons that the arts teach:

1. To make good judgments about qualitative relationships
2. Problems can have more than one solution
3. Celebrate multiple perspectives
4. Complex forms of problem solving
5. Limits of language do not define the limits of cognition
6. Small differences can have large effects
7. To think through and within a material
8. To say what cannot be said
9. Experience what can be had from no other source
10. The arts' position in the school curriculum symbolized to the young what adults believe is important

Public Policy: Art and Education

Motivated by the growing body of literature that illustrates the many benefits associated with learning in the fine arts, the federal government has established basic criterion for schools to follow regarding fine arts education. In 2001, the "No Child Left Behind Act" mandated that all teachers should be highly qualified to teach core academic subjects, including the arts. The act also founded the Arts in Education Model Development and Dissemination Grant Program, which seeks to incorporate the arts into elementary and middle school curricula. The program supports high quality teaching instruction in the arts and seeks to improve students' performance in the arts (U.S. Department of Education, 2002). Unfortunately, "due to budget constraints and emphasis on the subject of high stakes testing, arts instruction in schools is on a downward trend…This is especially true for students from lower-income schools, where analyses show that access to the arts in schools is disproportionally absent" (PCAH, 2011, p.vi).

In Texas, Senate bill 815 implemented TEKS, Texas Essential Knowledge and Skills, for all school subjects. In essence, TEKS is the standard for what students at every grade level should understand and learn with respect to the curriculum, including fine arts (Texas Education Agency, 2011).

Senate Bill 1, passed by the 74th Texas Legislature, charged the State Board of Education with clarifying essential knowledge and skills in the areas of the foundation and enrichment curricula. As stated in the Texas Administrative Code, "districts must ensure that sufficient time is provided for [K–5 and middle school] teachers to teach and for students to learn" fine arts and many other disciplines. At the high school level, districts must offer courses from at least two of the four fine arts areas (art, music, theatre, and dance) (Center for Educator Development in Fine Arts, n.d., p.11). To meet these standards, it has been mandated that the fine arts must be offered for all grade levels in Texas. Mandatory time must be allotted for students to take classes in the arts until grade 9, at which time students have the option to take a fine arts course or not (Texas Statutes, 2009).

Students in Texas must graduate from high school under the Recommended Program (default plan) or the Distinguished Achievement Programs (advanced placement), both of which require one credit of fine arts. Students also have the option to graduate from high school under the Minimum Program, which does not require fine arts, but only with the consent of the student, the student's parents/guardians, and a campus administrator. There is no arts requirement for college admission (Arts Education Partnership, n.d.).

Art Education in Bexar County

"The Arts Dynamic," a survey commissioned by the San Antonio Arts in Education Task Force, revealed that during the 1999-2000 school year, nearly 238,000 students were enrolled in 13 San Antonio public school districts. Over 70% of this student population was economically disadvantaged (Casanova and Merriam-Gourley, 2001).

The study demonstrated that only certain school districts provided students with fine arts instruction. The most disadvantaged schools offered minimum instruction in the fine arts, and elementary school children received the least amount of exposure in all areas of the fine arts. At the middle school and high school level, the emphasis on fine art education was limited and occurred only as an elective.

"Participation in the arts helps students improve social skills. Students with lower socio-economic status who had sustained involvement in theatre arts were show over time to have greater self-confidence, motivation and empathy than did their non-arts peers, according to a ten-year national study of over 25,000 high school students" (National Assembly of State Arts Agencies, n.d., p.4). In the many types of comparisons, "arts-engaged low-income students tend to perform more like average higher-income students, which suggest that the role of arts in developing competency may be especially important for students who otherwise feel isolated or excluded, e.g., English learners," (PCAH, 2011, p18). Despite state legislation that strongly recommends academic preparation in the fine arts, it is evident for the most part, San Antonio schools do not provide adequate time to teach students in the fine arts.

<u>Elementary School, grades K-5</u>

"The various symbolic ways of communicating through dance, music, theatre, and visual arts, along with the motor skills required in each discipline, heighten the on-going, open-ended development naturally occurring in elementary children" (Casanova and Merriam-Gourley, 2001, p5).

Elementary students produce creative and imaginative pieces that:

• Develop perceptual skills
• Use a variety of media in multiple activities
• Reflect knowledge of art history
• Show art as an expression of cultural experience
• Foster skills of evaluation
• Become more aware of their physical environment
• Extend and develop use of the senses
• Utilize inventive thinking
(Center for Educator Development in Fine Arts, [CEDFA], 2011a).

<u>Middle School, grades 6-8</u>

"The fine arts provide ways for a young person to express complex emotions, make individual choices, and exercise decision-making in a safe, affirming environment" (Casanova and Merriam-Gourley, 2001, p7).

Middle school courses lay the foundation for work at the high school level and allow students to:

• Express ideas, thoughts, and feelings
• Explore a wide variety of media
• Collaborate on group projects
• Relate art to social, environmental and political issues
• Mature in their abilities to observe experience and express themselves in effective and innovative ways (CEDFA, 2011c).

<u>High School, grades 9-12</u>

"At this point when students so clearly understand that the world is theirs to create, the fine arts become avenues for testing assumptions, exploring hypotheses, and inventing new systems" (Casanova and Merriam-Gourley, 2001, p9).

High school tudents participate in a variety of learning experiences, including:

• Vocabulary development
• Two and three-dimensional art making
• Exploration of historical and cultural context
• Practice in evaluation techniques
(CEDFA, 2011b)

Cultural arts organizations, in an effort to alleviate the lack of fine arts education in schools, provided outreach programs to students.

San Anto Cultural Arts (SACA) is a community-based, cultural arts organization that serves school aged children (elementary through high school) and their parent(s). SACA strives to cultivate and empower people of all ages throughout San Antonio (especially targeting the Westside youth), through arts and mentorship. Most participants who attend SACA also attend Title I schools, meaning that the Federal government has designated approximately 56% of the student population to be economically disadvantaged. Therefore, this program affords youth the opportunity to belong to a creative community, build life skills, and obtain technical and marketable job skills that will open the doors to higher education and employment opportunities (San Anto Cultural Arts, 2011).

Artpace, Inc. offers free, year-round art education for K-12 students through its artElements program. Features of the program include:

- *Artpace[3]* – touring program which includes a guest art speaker sent to the school before and after students take a field trip to Artpace
- *Teacher workshops* – in-services to equip teachers to develop curricula using contemporary art to explore and explain interdisciplinary topics
- *Semester program* – pairs a local artist with a class for a semester in which the students, artist, and teacher engage in lessons about contemporary arts and culminates with a site-specific public artwork for the school's campus

(Artpace, 2011)

Say Si offers year-round, tuition-free arts education programs to middle and high school students in visual arts, media arts, and theater. Its focus is "to develop artistic and social skill in preparation for higher educational advancement and professional careers" (Say Si, n.d.). Students also develop cognitive skills, including; problem solving, reasoning, decision-making, oral communication, teamwork and self-fulfillment.

Step Up for Arts Education. The San Antonio Arts in Education Task Force changed its name in 2010. Its mission of "promoting the arts as essential to human development and advancing the opportunities for equal access to superior art education for all in the San Antonio community" (J. Hinojosa, personal communication, February 2, 2010) is being advanced through several projects including:

- <u>Innovative Art Educators Scholarships</u> where "K-12 classroom and arts teachers are invited to apply for a scholarship to engage in artistic learning for their students or to provide professional development in an arts-related field" (Step Up, n.d.).
- <u>Shared Community Compact</u> where Rackspace Hosting and North East Independent School district partnered to provide Roosevelt High School and its six elementary and middle feeder schools with enrichment through facility upgrades, literacy programs, and arts education (Step Up, n.d.).

Conclusion

In the end, an education in the arts is beneficial at every age level. It is evident that "the arts are dynamic: intrinsically dynamic by themselves in uplifting and transforming the human mind and spirit, and extrinsically dynamic, a force for invigorating learning in all areas of the curriculum" (Casanova and Merriam-Gourley, 2001, p4). The primary purpose of an education is to provide children with the academic and intellectual skills necessary to flourish. However, the classroom is an ideal place for children to develop good self-esteem by supporting activities that emphasize proper social behavior, self-management skills, and creative expression. An education that includes music and fine arts can accomplish this task.

References

Americans for the Arts. (2009a). *Highlights from key national research on arts education*. Retrieved from http://www.americansforthearts.org/public_awareness/artsed_facts/highlights/multiple_arts.asp

Americans for the Arts. (2009b). *Arts and Academic Achievement*. Retrieved from http://www.artsusa.org/information_services/arts_education_community/resource_center_001.asp

Americans for the Arts. (n.d.). *Arts students outperform non-arts students on SAT.* Retrieved from http://www.americansforthearts.org/pdf/get_involved/advocacy/research/2011/sat_artsed11.pdf

Artpace. (2011). *artElements*. Retrieved from http://artpace.org/education/students-educators/

Arts Education Partnership (AEP). (n.d.). *State arts education policy database results: Texas.* Retrieved from http://www.aep-arts.org/database/results2.htm?select_state_id=33

Casanova, D., and Meriam-Gourley, N. (2001). *The arts dynamic: A survey and analysis of arts education in San Antonio area schools for 1999-2000 school year.* San Antonio: San Antonio Arts in Education Task Force. Retrieved from http://www.stepupsa.org/wp-content/uploads/2010/09/The-Arts-Dynamic.pdf

Center for Educator Development in Fine Arts. (CEDFA). (n.d.). *Art Curriculum Framework.* Retrieved from http://www.cedfa.org/teaching/curriculum/artframework.pdf

Center for Educator Development in Find Arts. (CEDFA). (2011a). *Fine Arts Programs in Elementary Schools*. Retrieved from http://www.cedfa.org/strengthening-programs/elementary-programs/art/

Center for Educator Development in Fine Arts. (CEDFA). (2011b). *Fine Arts Programs in High Schools*. Retrieved from http://www.cedfa.org/strengthening-programs/high-school-programs/art/

Center for Educator Development in Fine Arts. (CEDFA). (2011c). *Fine Arts Programs in Middle Schools.* Retrieved from http://www.cedfa.org/strengthening-programs/middle-school-programs/art/

Education Partnerships, Inc. (n.d.). *Fine Arts Education.* Retrieved from http://educationpartnerships.org/pdfs/FineArtsEducation.pdf

Eisner, E. (n.d.). *"Ten Lessons the Arts Teach": by Elliot Eisner.* Retrieved from http://www.oregonfoto.org/subroutines/eisner.html

MENC: National Association for Music Education. (2011). *Why music education? 2007.* Retrieved from http://www.menc.org/resources/view/why-music-education-2007

National Assembly of State Arts Agencies. (NASAA). (n.d.) *Research-based Communication Toolkit*. Retrieved from http://www.nasaa-arts.org/Research/Key-Topics/Arts-Education/rbc-toolkit-section3.pdf

National Assembly of State Arts Agencies (NASAA). (2006). *Critical evidence: How the arts benefit student achievement*. Retrieved from http://www.aep-arts.org/files/publications/Critical%20Evidence.pdf

National Center for Education Statistics. (2009). *Arts 2008: Music and visual arts*. Retrieved from http://nces.ed.gov/nationsreportcard/pdf/main2008/2009488.pdf

President's Committee on the Arts and the Humanities. (PCAH). (2011). *Reinvesting in Arts Education.* Retrieved from http://www.pcah.gov/sites/default/files/PCAH_Reinvesting_4web.pdf

San Anto Cultural Arts (SACA). (2011). *Our Community: Located in the heart of the "Westside"*. Retrieved from http://www.sananto.org/index.php?option=com_content&view=article&id=36&Itemid=65

Say Si. (n.d.) Mission. Retrieved from http://saysi.org/SaySi/about.htm

Step Up for Arts Education. (2010). *Projects*. Retrieved from http://www.stepupsa.org/projects/

Texas Education Agency. (2011). *Fine arts Texas essential knowledge and skills*. Retrieved from http://www.tea.state.tx.us/index2.aspx?id=2147499973

Texas Music Educators Association. (n.d.a). *Five-Year SAT score comparison: Texas all-state musicians compared to the national and state average.* Retrieved from, http://www.tmea.org/assets/pdf/All-State_SAT_Comparison_2009.pdf

Texas Music Educators Association. (n.d.b). *Students enrolled in fine arts courses score higher on the sat than those with no fine arts coursework*. Retrieved from http://www.tmea.org/assets/pdf/National_SAT_Comparison_High_Level_2006-2009.pdf

Texas Music Educators Association. (2011). *All-State student average SAT scores.* Retrieved from https://www.tmea.org/programs/all-state/average-sat

Texas Statutes. (2009). *Education code*. Retrieved from http://www.statutes.legis.state.tx.us/Docs/ED/htm/ED.29.htm

U.S. Department of Education, Office of Elementary and Secondary Education. (2002). *No Child Left Behind: A desktop reference.* Washington, D.C. Retrieved from http://www.ed.gov/admins/lead/account/nclbreference/reference.pdf

Winner, E., & Hetland, L. (2007). Art for our sake. *The Boston Globe.* Retrieved from http://www.boston.com/news/globe/ideas/articles/2007/09/02/art_for_our_sake/?page=full