Affinity Learning in Mathematics

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(Extracted from a paper in preparation)
September 20, 2001

I. Abstract

Teaching complex subjects such as mathematical modeling is intrinsically challenging. It is more so in a typical classroom setting. In this paper, we explore the use of technology to provide an electronic tutor that interacts with both teacher and student to provide a personalized and focused learning experience. Affinity Learning is an environment that captures the skills of a master teacher in a dynamic but simple technical embodiment and presents lessons and assessments online to a student. Initial results not only indicate that learning has occurred, but also distinguish male from female performance and give interesting insight into the learning process itself.

II. Introduction

Mathematical modeling of a phenomenon, event or process, is challenging. The modeler, or student in this instance, must often translate observations of objects, forces, and time sequences into descriptive and predictive equations. For the learner to comprehend what they are observing mathematically, they must have an intuitive understanding of what is occurring and the intellectual ability to abstract that understanding into mathematical representation. Teaching individuals to have these skills is difficult. It is believed that accomplishing effective learning of difficult topics can be best accomplished through a Socratic or tutoring method rather than through didactic or static text instruction.

Crowded classrooms and unavailability of teachers deeply skilled in specific complex topics frequently renders didactic instruction as the method of choice. Affinity Learning is a concept for using computers to leverage educators and provide instruction attuned to the skills of the student. In effect, we sought to build an electronic tutor. At the very least we hoped to prove that such a thing could help learning. Our initial effort, funded by a NSF Proof of Concept grant, has given results beyond our expectations. We find that not only can we influence learning, but that we can distinguish male and female learning characteristics and actually track the learning as it is taking place. The insight gained leads to many more questions such as "Can we predict performance by early student interaction and adjust course presentation to fit student characteristics?," "Can we distinguish poor presentation or assessments methods from poor student performance?" and "Can we adjust instruction based upon learner characteristics to increase student performance?"

The Affinity tool is based on relatively simple database-driven software. We have, in effect, used this tool to capture the teaching skill of a master mathematics teacher. In an online setting, the student is guided through a set of activities and assessments in accord with their skills and rate of learning. When a student outcome on a particular activity is unanticipated in the software/database, the teacher is solicited for help. In offering that help, the teacher designs a new activity and assessment that is appropriately incorporated into the environment. The Affinity environment grows from an initial state to more and more sophisticated capabilities.

II. Background and Principles for the Project Design

Our primary target goal was to increase the effectiveness of developmental mathematics courses through the use of technology. A developmental mathematics sequence initially was chosen because it offered an innately assessable discipline driven by a significant need. It has been noted that 72 percent of four-year institutions of higher education in the U.S. and nearly every (99 percent) two-year college offer developmental math courses, as do 93 percent of institutions with high minority enrollments (NCES, 1996).

Whether computer-based instruction is or is not superior to human instruction was in and itself an interesting question to our development team, and which generated a great deal of thought and discussion within our design team meetings. However, we felt that a purposeful blending of such instructional partners was an important key to the eventual success of our project. Human instruction is notably weak or missing in many developmental math courses, and many universities are reluctant or unable to commit scarce instructor resources to what are viewed as remedial courses. The learning environment we conceptualized within Affinity Learning provided the advantage of more interactive and personalized instruction than what is usually now available in developmental math courses. Often in such university courses, students work nearly completely on their own, left to work their way through a textbook with only a graduate student instructor available to answer questions and offer periodic assistance. We felt such students needed instructional help beyond their typical resources and setting, and we believed that well designed software, could provide such help.

Mathematical modeling was targeted as the primary content area within the project, because mathematical modeling is both an important topic in today's mathematics classroom, and an unusually difficult process to teach in the traditional classroom. Mathematical modeling can be defined as a mathematical process that involves observing a phenomenon, conjecturing relationships, applying mathematical analyses (equations, symbolic structures, etc.), obtaining mathematical results, and reinterpreting the model (Swetz & Hartzler, 1991). It is essentially a systematic generalization process, where the mathematical model (such as a mathematical expression or algebraic formula) attempts to describe the mathematical relationships for a group of problems or situations, and is refined over a period of time with additional testing or use of the model.

Mathematical modeling often requires considerable student involvement, which made it a rich instructional context for targeting within our project. Part of the difficulty in the instruction of mathematical modeling, is that considerable flexibility and feedback is often needed to work with the student (Smith, 1997). As a student's understanding evolves, their conceptual model may go through many different evolutions, hopefully becoming more refined over a period of time, and with more instruction and feedback. Often, if a formula can be used to represent the model, the formula evolution itself may somewhat represent the evolution in the modeling process. This characteristic of mathematical modeling makes it particularly useful for documenting and examining student thinking within the instructional process, and could eventually become a key feature in our instructional design.

Mathematical modeling is in essence a "scientific inquiry" process for mathematics, and can be thought of as being undertaken in a series of four stages, which become cyclical as the model refines. Four stages can be considered within the mathematical modeling process typically undertaken (Swetz & Hartzler, 1991). These stages include: Stage 1 - Observing and Discerning (observe the phenomenon or problem); Stage 2 - Conjecturing (proposing a mathematical or symbolic representation of the problem; Stage 3 - Applying Mathematical Analysis (converting relationships within the data based model to mathematical equations or expressions); and Stage 4 - Interpreting Results (test the model, and obtain results and interpret them in the context of the original problem).

Our proof-of-concept project was accomplished in three phases.

In **Phase 1** a specific sample module was designed and developed in the affinity learning environment. After considerable discussion, the project targeted the concept of mathematical acceleration as a rich content area for the demonstration of our design principles. We reviewed and closely examined a variety of potential mathematical models from high school and college classes that could be used within the content for the prototype. Master teachers from the public schools were key participants within these discussions. Embedded assessments were also integrated into the environment and built upon the tracking technology implemented in CLASS™ Project courses. The team also drew upon the concept of a Knowledge Garden being developed for the CLASS™ Project by Dr. Scott Henniger, from the University of Nebraska at Lincoln. **Phase 2** consisted of observing a sample set of students as they used the developing module. This provided a use sample for refining the software and interfaces, and also enabled us to develop a graphical representation of student progress through the module. Finally, during **Phase 3**, students were tested using the affinity learning environment and using a conventional environment. A concerted attempt was made to make both presentations as engaging and educationally rigorous as possible.

At the end of this three phase effort, we now have the following outcomes: 1) a demonstration module for the affinity learning concept as it relates to mathematical modeling within the construct of acceleration, 2) a graphical profiling process to track student progress students, and 3) a variety of related research papers and presentations describing our fundamental design principles, its resultant prototypes, and strategies for dealing with student learning within this context.

Our design principles:

In order to establish a vision for the project that was consistent with current literature, feasible, and our own experiences, our design team carefully conceptualized seven "design principles" for the project. Our project design principles are refined to be consistent with the vision of new technology based resources as recommended by documents such as the 1996 NSF document "Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering and Technology."

The design principles undertaken within this project targeted the instructional topic of acceleration as a context for the mathematical modeling process. The construct of acceleration is a common topic covered in a variety of developmental mathematics and science courses. Acceleration is also commonly taught in many remedial classes, where students are often nearly on their own, and left to work their way through a textbook with only a graduate student instructor available to answer questions and offer assistance.

Thus, our vision for the project was represented by our seven design principles, which are now described. These principles were used to continually help focus the project, and to help ensure that the project was designed to produce a solid educational environment, conducive to individual student learning.

Design Principle 1) The adaptive instruction of the project seeks to use technology to help students learn through involvement with real life problems, real life data, and true examples of mathematical modeling as they apply to today's world.

The use of real life problems, data, and tools within the context of technology based mathematics instruction has long been recognized as a beneficial contribution to student learning (Corbat, 1985). The availability of the Internet has expanded the teacher's selection of such modeling resources and software, which are now available to a much greater extent than they were even five years ago (Harvey and Charnitski, 1998). For instance, real life examples related to optimization were normally not taught until Calculus, but with the appropriate graphing technologies, students at lower grade levels can learn to interpret and build mathematical generalizations based upon graphical information as well as the traditional calculus approach. This exposure in the lower grades (i.e. algebra or geometry) would set the stage for much more meaningful problem solving and mathematical modeling when the same students reach Calculus and study optimization as a formal topic.

Design Principle 2) The adaptive instruction within the project sought to actively rather than passively involve students, in deep conceptual questions and encourage them to be both dynamic and flexible in their thinking and problem solving.

A fundamental instructional idea behind mathematical modeling is that students, through modeling activities, discover patterns and consistencies in data that will allow them to test, refine, and build generalizations by creating a "mathematical machine" which represents a particular situation (Smith, 1997). This "machine" would provide them with a means for conjectures and predictions that might be tested using data sets, or systematic trials. Thus, the mathematical modeling process by a student typically goes through several modifications or refinements in order to produce a model which is more accurate, faster, or efficient. The creation of such a mathematical machine by a student, and its testing and refinement, is typically a very interactive process. Such systematic thinking within the mathematics field by a student is similar to they might undertake using the scientific method within a science class, and parallels that process closely. It also helps students understand that true mathematical application is much more than the mere routine application of formulas and strategies that they may have experienced in some mathematics instruction. Our project developed software that was very interactive with the student, and helped students work through a series of "instructional nodes" which helped individualize the student learning experience. This node-based structure is described later in the paper.

Design Principle 3) The adaptive instruction system sought to be an additional resource to teachers and classrooms, rather than a replacement for these valuable assets to student understanding.

The project we developed sought to enhance rather than replace the important synergy that often happens between a teacher and student in the learning process. Within this context, our project tried to build instructional nodes that might facilitate the shared thinking between a student and their teacher, or a student and other students.

Design Principle 4) The adaptive instruction sought to enhance human interaction, by connecting students more effectively with the teacher, their peers (other students), and appropriate mentors (professionals) during the mathematical modeling process.

Based upon the student level, interests, and local resources and professional availability, the system we conceptualized also would permit opportunities for students and professionals to work together electronically and collaboratively to confront modeling challenges as a "affinity learning group". Similar to electronic special interest groups or listservs, but more focused on a particular task or set of activities, these affinity learning groups might move forward together to share ideas and activities occurring on the system. In this way, students can tap the thinking of other students, as well as designated professionals. This targeted capability for the prototype was well planned within the project, but funding levels didn't permit the direct integration into the project prototype.

Design Principle 5) The adaptive learning system seeks to help with the ongoing assessment of student understanding, through a systematic use of embedded assessments, as well as student self-assessment.

The systematic assessment of student understanding is a very important piece of the interactive technology integrated within the project. As educational technology continues to rapidly advance, new assessment opportunities and techniques are surfacing based upon these new technologies (Baker & O'Neil, 1995). Within this project, the use of assessments, which are carefully integrated into the instructional environment, or “embedded”, are targeted within the project design. For example, in an instructional activity where a student uses a spreadsheet to examine patterns of data within the mathematical modeling process, the system documents what variables the student decides to use in the formulaic relationships. The project was successful in developing a graphical strategy for displaying student pathways through the instruction, which provides an excellent insight into student understanding. This graphical strategy is discussed later in the paper, and has been a key outcome of the development work, and a promising mechanism for representing student progress through an online curriculum.

Our design work has shown us that there is indeed a rich context of potential assessment information that exists within an on-line or technology based learning environments, and that the technology itself can indeed be a very useful tool in the organization of such information as described in some research (Mathies, 1995). In fact, assessment variables, which might be stored within the context of such student profiles, are quite numerous. These variables can include a wide variety of student performance information. Some examples include the quality of the questions asked within electronic dialogue with the teacher or peers, the speed of response within a simulation environment, the approach used to set up on-line experiments to test data, the content information self-selected by the student to review. Student self-assessment can also be very rich within this context, and students might reflect periodically upon their own levels of understanding.

It was recognized within our conceptualization process that any assessment would of course have some inherent degree of error in examining or predicting student understanding. An important component of the current prototype design planning in the project was then trying to identify potential “nodes” of student understanding, or related “nodes” of student misconception, within the content area of acceleration, based upon previous work of researchers in this topical area. We have defined a “node” to essentially be a key point within a student’s understanding related to a particular content area or process. For example, within our acceleration content area of the prototype module, such a node was something as direct as recognizing that the student understands that velocity is changing over a period of time. It was also recognized that some student presence at a particular node of understanding might initially be less defined or "fuzzy", until the system has adequate data from the student to determine whether a particular level of understanding or "node" has been truly achieved.

Design Principle 6) The adaptive instruction sought to assist students in a systematic learning process, by carefully targeting instruction based upon their current levels of understanding.

The design of the project also sought to support that students would most likely work from current levels of understanding (or achieved nodes as mentioned earlier), and are able to access content information as they are ready for it. The ability to move easily and systematically through content is an important component of any successful online instructional endeavor, and particularly when faced with the mathematics discipline (Harvey and Charnitski, 1998). For this prototype, the project built upon previous successes and expertise in instructional design already established within the CLASS project (Communications, Learning, and Assessment in a Student-centered System) underway at the University of Nebraska at Lincoln.

Design Principle 7) The adaptive learning system sought to strive to assist students in the learning process, by acting as a non-threatening coach or assistant, which patiently helps them clarify their thinking process, examine possible approaches to the problem, and test possible solutions.

Within the design philosophy and process undertaken in the project, student control was perhaps the most important design feature being incorporated. The vision for the project is one in which the student helps initiate, monitor, and direct their own learning process. The independent nature of the mathematical modeling process makes this a key design feature needed for any system, which strives to assist in the modeling process (Smith, 1997). In fact, as described by Smith, the first independent run through the modeling process is often the most difficult. The education design within this project is paying particularly attention to this typical difficulty. Thus, the prototype developed in the project seeks to assist students in learning how to initiate a mathematical modeling endeavor by helping assist their choice of modeling subtask, presenting the subtask appropriately, and delivering their the appropriate tutoring, and relevant instructional intervention, as needed. Facilitating such a systematic control by the student was also one the most difficult design challenges that we are facing in the project, and required a variety of potential pathways through the instruction.

It was indeed a daunting task to build an interactive and technology-based instructional prototype that truly followed the seven educational design principals set out by the team, and described in this paper. Each principal is itself was an individual design challenge, and inherent with its own set of individual challenges when trying to be operationalized within the context of one or more components of a working system. However, we were able to build upon a solid foundation of earlier work, a commitment to innovative instruction and learning, and an ongoing dialogue with numerous colleagues. We believe that we were able to demonstrate how such system might contribute to the achievement cycle in mathematics education: curriculum, assessment, instruction, and learning (Glatthorn, Bragaw, Dawkins, & Parker, 1998); a cycle which is becoming all the more important with the growing commitment to standards-based curriculum, performance assessment, and related student achievement within our country.

III. Prototype Affinity Environment

The Affinity tool is conceptually simple. Execution was challenging in this first instance. We also have unanswered questions as to the growth of development complexity as the complexity of the teaching domain grows. This question will be answered in further experiments. The Affinity tool is now being applied in two other discipline areas.

The easiest was to conceive of Affinity is to think through a simple teaching exercise. In teaching a child to ride a bicycle, one can break that down into relatively small lessons. Each lesson could, and in this case does, consist of an activity and an assessment. For example, one might demonstrate the handlebars by showing them to the child and explaining that turning the bars to the right causes a right turn, and to the left a left turn. The child is then asked the purpose of the handlebars. If the response is that they cause the bike to turn, then the teacher can proceed on to the pedals. If the child responds that the handlebars cause the bike to go faster, then some remedial activity is needed. The remediation could be an enhancement, or presentation in greater granularity.

Each one of the small lessons in the example is, in our context, known as a "fuzzy node." A fuzzy node consists of an activity, an assessment, and an identified number of outcomes. An outcome might be "correct" or "erroneous". The nodes are called fuzzy because we recognized early in the development work that any node could be broken into smaller, nodes of higher granularity. How does one predict correct or erroneous? In the case of mathematics it is often reasonably straightforward. The teacher can predict the case where the student multiplied rather than added or divided, etc. It is foreseeable that not all outcomes will be predicted. In the case of an unexpected state, the student is notified to contact the teacher. The teacher can then generate or help identify a new fuzzy node to take care of this occurrence.

The Affinity environment interconnects the nodes based on the outcomes. Correct outcomes lead to subsequent activities, incorrect outcomes lead to remediation. Unexpected outcomes lead to new fuzzy nodes. In other words, we seed the "knowledge garden" with what we can predict. As the tool is used, the garden is invested with new nodes and grows. As experience is gained, the network of nodes grows leading to a more capable electronic tutor.

A high school master teacher in mathematics developed the nodes and node structure for the acceleration example. Instructional designers expert in online presentation developed the activities based on the teacher's specifications.

The online presentation was in HTML with Java augmentation. Database operations were performed using MySQL and PHP scripting.

IV. Field Tests and Results (Preliminary and Summary)

The acceleration prototype presents the student with background material on acceleration. It includes a simple demonstration of a car accelerating wherein the student can change the initial parameters such as initial velocity and acceleration. The final activity is to test the student's equation for acceleration. All of this is done online. The student had access to colleagues and the teacher at any time during the experiment.

For prototype refinement, the project used a series of three different class sized groups of students (25-30) to help refine the software, which included college students, and high school mathematics and physics students. The students worked through the software module, and then made suggestions, as well as commented on any confusion or frustration that they experienced in different parts of the module. A focus group setting was used to gather this feedback for potential refinement of the prototype, which was then addressed by the programming team. The prototype refinement sessions then led to a more formal field test of the prototype.

The field test was used to examine the effectiveness of the software for working with students already responsible for learning about mathematical modeling as it related to the concept of acceleration. In this pilot study, the students were divided into two groups. One group used the prototype module, and the other group used a compatible paper and pencil activity.

As baseline information, students were surveyed related to demographic variables including gender, cumulative grade point average, and age. They were also asked about their attitudes about mathematics, science, computers, and group work, using a five point Likert scale, with questions such as “I like math” or "I prefer to do projects on my own, not in a group." Students were also surveyed following their work with the module in order to make any suggestions, and to report what they liked, what they disliked, and how the instructional activities and developed prototype might be improved.

Before working with the module, or the paper and pencil activity, students were pre-tested and post-tested on the concept of acceleration using a short multiple choice instrument, and asked to examine mathematical models representing the concept in various cases. Related mathematical concepts were also involved in the cases, and included basic concepts such as velocity, variables, linear and parabolic relationships, reading a graph, and interpolation and extrapolation of values from a table. The individual questions focused on specific accelerated motion cases with non-zero velocity, that included graphs of distance vs. time, velocity vs. time, and data tables of related parameters and variables.

With reference to the high school students participating, pretest scores indicated compatible treatment groups for study with means of 52% and 55% for the online and paper vs. pencil groups respectively ($t = -.42$, $p < .68$). The posttest results suggested a small advantage for the learning involving students in the prototype use, with an average posttest score of 62% for students using the online module, as compared to 52% students using a paper and pencil format for the instruction. A t-test analysis ($t = 1.69$, $p < .05$) confirmed that this difference, although relatively small, was statistically significant.

As with the initial development sessions, students made suggestions on the continued refinement of the prototype module, and any preferences related to the prototype structure. In general, the field test students reported a strong preference for the interaction that the computer provided within the module, and particularly the simulations within the program. The students had less of a preference for the narrative or reading based aspects of the module, and generally confirmed that interactivity was of key importance for their learning preferences.

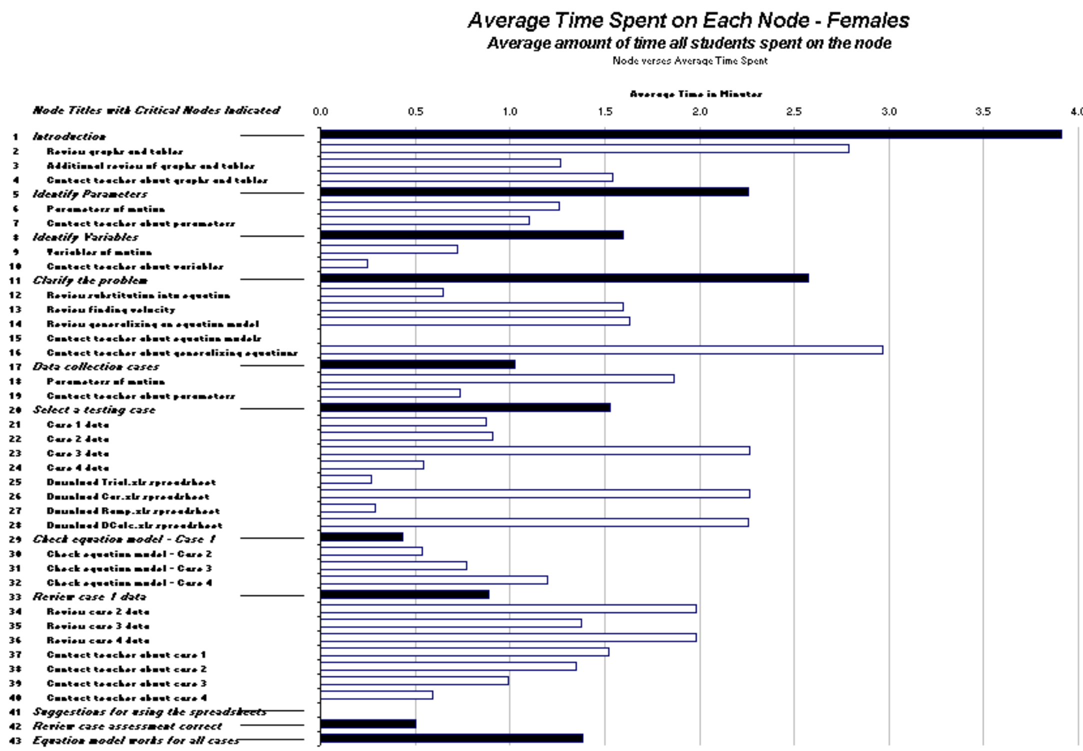

Figure 1 Average Time per Node, Female Students

At this early point in the analysis it is interesting to look at the performance of students. Figure 1 indicates the average time spent by female high school students on each node. Figure 2 indicates the same for male students. Note the differences. Girls tended to spend more time in the introductory nodes and in the final testing. Boys, on the other hand spend less time in the introduction and more time in “contact the teacher.” Girls performed better in the pre/post test assessment – hence they appeared to learn more.

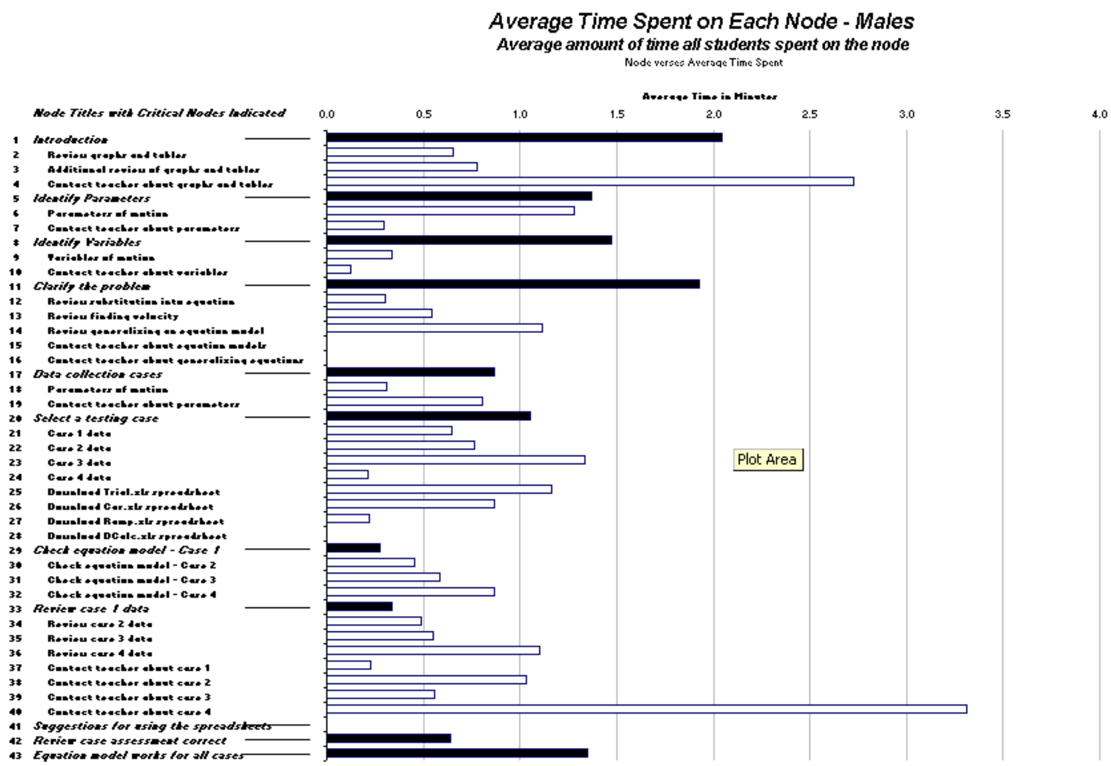

Figure 2: Average Time per Node, Male Students

Is there a sex discriminator in the use of online presentations? Had we inadvertently developed a presentation/assessment environment that favored females? According to our expert high school teacher, we just demonstrated a known fact. Girls in the 10th grade did not like making errors and they wanted to please their teachers. Boys in the same grade were motivated to finish the activity as quickly as possible and with as little expended energy as possible. The important lesson for us is that the tool did demonstrate a known characteristic of learners.

Figure 3 shows the nodes visited over time by a particular female student. In general successful traversing of the fuzzy node network is indicated by a timeline flowing steadily down. Upward jumps indicate return to earlier nodes or to earlier remedial activities. Note that there is some fluctuation in the beginning as the student becomes familiar with the topic and the tool. The timeline demonstrates a noticeable downward shift which we've come to call the "Eureka moment" when the student begins to comprehend the topic. The fluctuation at the end indicates either that the final assessment of the student's equation is intrinsically hard or that we did a poor job in aiding that testing online.

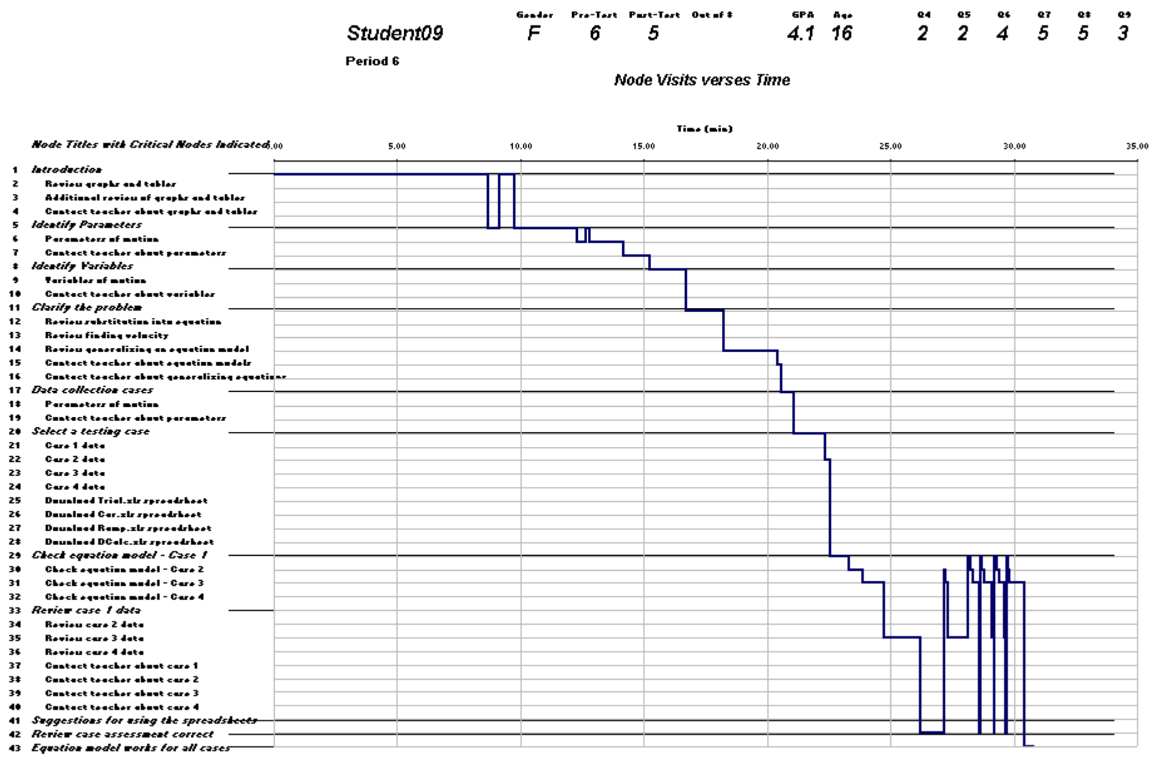

Figure 3: Female Student: Node Visited vs Time

The exciting thing about Figure 3 is that it demonstrates learning. We can watch student learning behavior very intimately as they tackle a complex topic. Many questions can be raised. Can we predict from early node performance how a student will perform on later nodes? If we can, then we can tailor the nodes to fit that student's learning characteristics. Can we discriminate poor presentation and assessment methods from student performance? If we can, then we can improve the presentation and assessment virtually continuously as the tool is used.

VI. Final Comments

This paper is contains material extracted from a longer paper in preparation. Its intent is to give a general introduction to the topic of Affinity learning and more generally to the possiblities of using technology to enhance learning. We have much to do to refine both the tool and our understanding of its application. But we are convinced that we have positivily impacted learning, that we can watch learning take place, and that we have raised more questions than we have answered.

VIII. Publication and Presentation List

The project has already generated a series of peer-reviewed papers, abstracts, and conference presentations. Targeted dissemination groups included professional associations related to mathematics education, instructional technology, and education. These dissemination related activities are listed below.

Grandgenett, N.F., Ostler, E.O., Zygielbaum, A., (2001). Mathematical modeling within a technology based learning environment: A process for adaptive instruction. Refereed presentation at the Joint Mathematics Conference, New Orleans, Louisiana, January 2001.

Grandgenett, N. F., Zygielbaum, A, Hamersky, S., Ostler, E. (2001). Helping elementary education majors brush up on mathematical modeling: Insights from a field test of a new online learning prototype. Published in the Proceedings of the Society for Information Technology and Teacher Education, Orlando, Florida, March 2001.

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X. Acknowledgements

The work on this curriculum-based Proof-of-Concept project relied on the considerable expertise and partnership of many professionals. The authors gratefully acknowledge the contributions of Steve Hamersky, Omaha Catholic Archdioceses Schools; Bob Pawloski, Elliot Ostler of the University of Nebraska, Omaha; and Roger Feese, Scott Henninger, and Char Hazzard of the University of Nebraska – Lincoln.

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