From robotics to semiotics: Using robots and graphing calculators to provide context for traditional algebra skills

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Abstract:Many of the national commission reports continue to call for technological literacy and student participation in problem based learning. Mathematics teachers who feel pressured to prepare their students to perform on standardized paper and pencil measures often are still not willing to sacrifice instructional time by involving their students in what they commonly see as "enrichment activities. However, an engineering based approach to teaching and learning using mutually supportive technologies provides opportunities for students to be involved in authentic types of design problems in a way that augments traditional semiotic processing. This paper explores how mutually supportive technologies such as graphing calculators and classroom robots can be used together to engage students in problem solving and design-based activities, which remain focused on the important symbolic processing ideas from the curriculum.

Introduction:

Recent education standards and reform documents such as the updated National Educational Technology Standards for Students (ISTE, 2007) along with older ones such as the Secretary's Commission on Achieving Necessary Skills (SCANS, 1992) continue to "bookend" a reoccurring spectrum of messages and define a clear pattern for the future of information technology and the role it plays in the mathematics classroom. The messages are simple… technological literacy is an essential part of job readiness, responsible citizenship, and life skills. Most *academics* would probably agree. Many scholars also agree that students should develop these essential technology skills in the context of learning and solving problems specifically linked to academic content (Baker and O'Neil, 2003). Yet in mathematics classrooms across the country, student opportunities for engagement in applied problems are still routinely passed over in lieu of guided practice that more closely mimics how students are assessed on high stakes, standardized tests.

Though often motivating and academically beneficial in their own right, applied-type problems tend to interrupt the flow of efficient lecture focused pedagogy, and often are not designed and executed to properly reinforce the semiotic processes that are thought to be the important formal outcomes of mathematics instruction. Given the choice, many teachers will allow the textbook scope and sequence to guide the coverage of mathematical topics and ideas. Further, teachers tend to question where broad based, applied problems actually fit into a curriculum designed to service specific, narrow, and easily measured didactic processes. However, we may be underestimating the power of episodic knowledge gained from application, or engineering as it were; even when the focus of instruction is on processing mathematical algorithms. An oversimplified suggestion would be to consider the following: in order to involve students in authentic, practical, and innovative mathematical learning, the formal semiotic processes, which are so often the focus in traditional mathematics classrooms must not be ignored or replaced, but rather, be augmented with opportunities to engage students in technology-based design and engineering processes using the textbook-based mathematics they are learning. In essence, the topics that we know are tested are still the focus of instruction, but they are supported in memorable and meaningful ways; ways that more powerfully illustrate the ideas than is possible with pages of homework problems from the text.

STEM education provides a way for traditional symbol manipulation to be applied through focused efforts in the natural integration, articulation, and differentiation aspects and content of Science, Technology, Engineering, and Mathematics. The dynamic nature of advancements in these core areas of STEM, and in particular, information technology, continually provide new opportunities for teachers to share current developments with their students in a rapidly advancing technological environment by providing relevant context to the more traditional topics they teach. This paper will provide an overview of a technology rich, engineering-based contextual model using innovations in robotic and graphing calculator technology as a way to enhance formal mathematical semiotic processes in introductory levels of algebra and beyond.

“Engineering” mathematics instruction:

Observation reveals that the majority of traditional coursework in algebra is based on semiotic processing, which relies uniquely on patterned sequences and protocols. Steen (1990) states that, “mathematics is an exploratory science that seeks to understand every kind of pattern that occurs in nature, patterns invented by the human mind, and even patterns emerging from other patterns. To grow mathematically, children must be exposed to a rich variety of patterns appropriate to their own lives through which they can see variety, regularity and interconnections.” Unfortunately, textbook-based curriculum continues to dominate in math classrooms and still falls short in providing relevant illustrations of naturally interconnected STEM concepts and patterns. On the other hand, thoughtful contemplation about textbook topics and instructional methodologies can lead to opportunities to engage students in engineering-type problems that truly reinforce the semiotic processes that are so popular in texts and on paper and pencil tests.

Engineering, as a pedagogical model for mathematics, admittedly is not an overly popular mode of instruction, perhaps only scarcely considered and probably used even less. Yet, engineering projects have the distinct advantage of motivating students with problem-based, hands-on activities while providing unique perspectives to the traditional mathematics curriculum (Coppola & Malyn-Smith, 2006). Engineering models can also provide a rich set of contexts where various symbolic patterns can be investigated, extended, and applied in physical environments. Advancements in information technology have perhaps made engineering and design based pedagogies much more possible (and certainly more timely) through interactive computer simulations and even more authentic projects such as programming external devices like robots. Moreover, robots and tools such as graphing calculators can be extremely powerful when used together as mutually supportive technologies, each providing greater extended contexts and frameworks for the other.

The suggestion that mathematics is to be *used* rather than simply *studied*, alters students’ and teachers’ perceptions about what mathematics is and how it should be learned, and the *use* of mathematics is what engineering is all about. In problem-based learning contexts, students must pay particular attention to the processes and patterns by which a product is improved, whether that product is the programming of a robot or the processing of an equation. The project-based explorations considered in this manuscript rely on mutually supportive use of the graphing calculator and a classroom robot; a short list of instructional considerations and assumptions; and a unique lesson planning model. A brief illustration of each will be given in the following sections.

Mutually Supportive Technologies:

The robot is a programmable device somewhat akin to a remote controlled car, but has the advantage of interchangeable add-on devices. These devices would include data collection capabilities such as bump sensors, cameras, GPS, and even sound, temperature, and light probes. The direction, speed, and other activities of the robot can either be controlled manually by the driver using a remote control, or automatically by a set of pre-programmed instructions. Naturally, the robot itself provides a myriad of opportunities for students to investigate force, motion, friction, vectors, coordinate graphing, light and sound intensity, and other topics of interest in STEM classrooms, but the real power emerges through the use of mutually supportive technologies like the robot/graphing calculator combination.

With a programmable interface protocol between a computer (which would typically be used to program the robot) and a graphing calculator, the robot could be made to follow directions provided by the programming feature of the graphing calculator. For example, a student might program the function f(x)=2x-3 into the graphing calculator and conjecture, observe, or record the resulting path of the robot. A student might guess that the robot's path be very similar to the line showing on the graphing utility. If the student then changes the function shown on the calculator to reflect a new slope or axis intercept, the robot would respond by following the appropriate path on its grid. Inversely, the robot itself could be remotely controlled by the student and periodically collect location data in the form of ordered pairs (GPS application) as it is driven across the grid. The robot would feed the information to the graphing calculator via computer, which would then be graphed as a symbolic function or relation on the calculator. Students could verify how the transformational coefficients of any given equation affect the direction of the robot, and also how any unique path yields an equation with coefficients that reflect the nuances of that particular path.

Likewise, students could program a specific path for the robot to follow using the function notation illustrated in the text, and then move the robot by adjusting the transformational coefficients for the various types of functions seen in the textbook practice exercises. They could then verify the accuracy of their programming by observing the actual path of the robot and comparing to the shape of the graph on their calculator, and again with the picture of the graph in the solution manual. In the case of this example, the only real programming changes a student might be making would be to change the coefficients in the equation in the calculator. This would allow the student to concentrate on the important mathematical ideas without being distracted by complicated programming code. Of course, the programming could be more involved if the context called for it. The activity could easily be extended by designing a more sophisticated route that the robot must follow. Want your robot to slalom around pylons on the graph? How about a Sine curve?

How Important Didactic Mathematics Content is Supported:

The concept of mutually supportive technologies described in the last section is used to augment didactic mathematical skills in a number of ways. First and foremost, traditional algebra skills are introduced, learned, reinforced, and applied in an environment that relies on the teacher, the text, practice problems, and application with graphing calculator and robot interaction. The careful integration of all these instructional components provides a richer, deeper mathematical experience, but one that remains somewhat focused on textbook based processing ideas. Second, the graphing calculator and robots are programmed using the symbols and processes of mathematics rather than with a separate programming code that could potentially distract the student from the mathematics being learned and take valuable exploratory time away from the learning environment. Therefore, students are more likely to directly transfer the knowledge of mathematical symbols and processes learned in this kind of applied format to congruent paper and pencil activities.

How the mathematical content is supported pedagogically is as important, or perhaps more important, than the technology being used. The following list of considerations and assumptions will hopefully guide the discussion into a productive use of mutually supportive technologies.

1. Consideration: What are some important things that robots do and how do they involve the mathematics in the texts?
2. Consideration: What does the graphing calculator do and what does it tell you about the information in the text?
3. Consideration: How is what the graphing calculator does different than what the robot does, and how can they help each other?
4. Assumption: the technology devices are not used to their own end, but rather to broaden the experience and production of other elements of the lesson.
5. Assumption: Students will be more motivated to solve traditional textbook problems using the robots and graphing calculators
6. Assumption: Students will gain meaningful experience with the graphing calculator earlier and have a greater appreciation for how engineers might use such a device.
7. Assumption: Good mutually supportive technology based activities do not happen by themselves and cannot be efficiently implemented without how they consider the important curriculum topics.

A lesson Plan Alternative that Makes Engineering Lessons Possible:

There are many different kinds of commonly recognized lesson plan formats, but one that is especially powerful is one that naturally allows for many different permutations of the same lesson using lesson components that help differentiate instruction or emphasize various points of the lesson. The lesson plan format being illustrated below uses a modular design (referred to as the *Vowel method*) that allows for the lesson components to be interchangeable and selected by teachers based on individual lesson needs. The AEIOU (vowel) components are designed as follows: A- Asking Questions, E - Exploring Concepts, I - Instructing Concepts, O - Organizing Learning, and U - Understanding Learning (or assessment). With this Vowel strategy, a well-established base of critical and well done lesson components will allow for a flexible retrieval of lessons and lesson components, as desired by a teacher using the curriculum ideas they deem most important, and the technologies most appropriate for illustrating and supporting the critical processes and concepts. The AEIOU method allows a user to select individual components of lessons within a five-part model of lesson planning, so that each component can stand alone, or can be easily removed from a lesson if desired by a teacher. Lesson components could even be replaced with a component of the same type, for a slightly modified lesson. The AEIOU lesson components are further detailed below:

A – Asking questions: This component is designed to facilitate an initial interchange of questions and ideas. An ***A*** component may include a prompt-type question in an engineering or scientific format as a model of what good questioning might look like. These ***A*** components may also included video clips, graphs, scenarios, and other hooks to empower students to become curious and ask questions.

E – Exploring concepts: This component helps students to study, experiment, conjecture, and to instructionally play with the robotics equipment in the context of the questions that were asked in the ***A*** component.

I – Instructing: This component is the only static component of the lesson plan and is designed to instruct students in the formal semiotic processes of the STEM topic that they are studying. All ***I*** components are designed to service a broad range of grade levels by separating topics into vertically articulated units: *recognizable* terms, *conceptual* terms, *mathematical* terms, *process* terms, and *applicable* terms. For example, beginners might explore a topic like slope through *recognizable* terms such as “Steepness” whereas advanced students might touch on the *application* of slope by exploring changes in slope based on what they see the robot do during their experiments.

O – Organizing learning: This component is designed to allow students to participate in a guided practice environment where they might create graphs, develop charts, solve problems, and make decisions based on what they have learned from the ***I*** components as well as what they have observed from their questions and explorations in the ***A*** and ***E*** phases.

U **–** Understanding: This component is designed around effective ways to assess how well the various ***I*** components have been addressed for students. The ***U*** components include a number of unique assessment instruments that range from short quizzes, games, to tests and worksheets, to projects, to interpretive writing.

Conclusion:

The lasting benefits of technology based instruction are varied and most certainly subject to a number of factors that having nothing to do with technology; however, deliberate efforts to articulate what mathematical topics are most important, and to define what role technology plays in how those topics are taught and learned will help ensure that technology is used in the most beneficial way possible… at least for now By especially considering how technologies can mutually support one another, we add a powerful dimension to how students perceive technology and its place in learning. Equally important to consider is the nature of how technology is used by students in acquiring and mastering specific mathematical topics. The assumption of merit will often be overshadowed by the "wow" factor that seems to be part of every new technological advance, but the question of how these advancements support mathematical learning will likely become a continually more complex question. A point in time may even arrive where what is considered important mathematical information will not be decided by what evolves in successive chapters of a textbook, but rather by what allows us to solve mathematical problems in ways we have not yet considered.

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