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Nevada Teachers Integrating Engineering into Science

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Introduction

The Teachers Integrating Engineering into Science (TIES) Program is a collaborative project among faculty from the College of Education and the College of Engineering at the University of Nevada, Reno and teachers and administrators from four Nevada school districts. The TIES partnership presents opportunities for both university professors and middle school science teachers to work collaboratively for the development and implementation of best practices in science and mathematics education. This paper describes our project, which is currently in progress. The two-part focus of the project is to first, provide professional development for 7^{th}-8^{th} grade science teachers to upgrade their content knowledge in engineering and learn integrated technology that supports effective science and mathematics instruction, and second, to facilitate the teachers in developing three engineering education modules for their classrooms. The modules include engineering design activities and are aligned with district and state standards for science and mathematics. Based on a review of current literature in engineering and science education, we developed a best practices model we call the Triangulated Learning Model (TLM) that was presented to the teachers as the delivery mode for the modules. The TLM employs three major elements designed to reinforce student learning: Simulation, Construction, and Connection. A variety of classroom and interactive Web-based learning activities are used throughout the TLM in order to reach a wide range of students.

Theoretical Framework

This project draws heavily upon the research in scientific inquiry, teacher efficacy, and engineering education. The engineering design modules developed by the teachers will provide a rich opportunity for their students to engage in scientific inquiry. The process of inquiry is critical to scientific literacy.[1,2] Improving scientific literacy among teachers of science has become a national goal. The report to the nation by the National Commission on Mathematics and Science Teaching for the 21^{st} Century[3] identifies professional development as prerequisite for a well-qualified teaching force and encourages teachers to take responsibility for their own professionalism as they work to improve their skills. The Commission also stresses the need for professional development that provides opportunities for teachers to upgrade content knowledge and to learn how to integrate technology into the teaching of mathematics and science.

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The National Staff Development Council standards advocate for professional development experiences that are research-based and that use content to increase student learning and development. Teaching teachers how to conduct science inquiry requires hands-on, situation-specific experience, an approach advocated by a number of science education researchers.[4-6] The result of effective professional development experiences often increases teaching efficacy, which is broadly defined as a situation-specific expectation that teachers can help students learn.[7,8] Efficacy expectations influence a teacher's thoughts and feelings, their choice of classroom learning activities, the amount of effort they are willing to expend, and their persistence in the face of obstacles. Over the past two decades, researchers have found important correlates to teacher efficacy.

Researchers using the Science Teaching Efficacy Belief Instrument[12] have found teacher efficacy to be positively related to early field experiences for pre-service teachers,[13] teaching performance,[14] and pre-service teachers' success in and enjoyment of student-centered instructional strategies.[15] Teachers with high efficacy are more effective, their students perform at higher levels on standardized achievement tests, and their students have more positive attitudes toward the content areas taught by these teachers.[7,9-11] Teachers who exhibit high teaching efficacy are more likely to spend the time needed to thoroughly develop science concepts in their classrooms.[16] We believe that as teachers work and associate with engineering professors to develop the teaching modules, their science teaching efficacy will increase.

Engineering design activities are a powerful strategy for the integration of science, mathematics and technology and for engaging a broad population of students. The natural and physical sciences are replete with examples of complex systems that employ engineering principles of design that could provide relevant and standards-based content for integrating engineering into 7th and 8th grade science classes. Yet most popular science textbooks for grades 4-12 incorporate little if any engineering content or activities.[17] The development of the TIES engineering design modules drew upon the work of researchers who have developed successful programs that integrated engineering content into science classes or who have provided after school engineering-based programs to middle school students. Several researchers postulate that design challenge activities effectively engage middle school students in the engineering enterprise.[18-20] Components of an effective engineering design experience include a focus on function as well as structure,[18] design as an iterative process,[18-20] team-building activities,[20] and cooperative learning and mentoring.[19,21] Research also suggests that initial prototype designs and alternative methods of recording and presenting results are successful methods for reaching a broader range of student abilities,[19] and that middle school students can meet cognitive goals focused on the engineering design process using a Web-based learning environment.[22]

Teacher Professional Development Component

Eight science teachers from 7th and 8th grade classrooms throughout Nevada were recruited to participate in the teacher development course. Teachers were paid a stipend that covered the cost of their tuition for a three-credit graduate course. The course was cross-listed in the Department of Curriculum & Instruction in the College of Education and in the Department of Civil Engineering in the College of Engineering. All but two of the teachers took the course for engineering credit. Three 10-hour sessions were planned for the teachers that included half a day

Friday and all day Saturday. Major tasks of the course included learning engineering content and developing the engineering design modules, which included designing a java applet for the simulation activity for the Web page. Teachers also received instruction in advanced assessment strategies and scientific inquiry pedagogy. Between session instruction and collaboration was done via the Web through WebCT. Teachers logged on to our class webpage and answered weekly discussion questions relative to course readings on science inquiry, assessment, standards mapping, and teaching strategies. They also met in their development groups in chat room format to develop preliminary plans for their modules.

Module Development

The module format was standardized and included lesson plans, classroom-based and interactive Web-based learning activities, assessments, and materials. Each module focused on a science topic that was aligned with district and state science content standards for which teachers were accountable. Topics for the modules were within the adopted curriculum, but with a twist. If, for instance, the module topic was force and motion, it was not enough to just teach *about* force and motion. They had to design a sequence of learning experiences for their students that allowed the students to actually design and build something using the engineering design process that would cause students to learn directly the concepts of forces and motion. Once the topics were selected, teachers identified sub-topics and concepts that became the focus of the series of lesson plans for their modules. An important component of the module development was the design of a java applet for the simulation element of the Triangulated Learning Model (TLM). The applets were designed by the teachers and were then given to our programmer to complete and upload to our Web page.

Teachers worked in small groups to develop the modules. The format for assessments was standardized across modules so student achievement could be compared across schools. The development of the module assessments involved a rigorous process of item development that was facilitated by the university professors with expertise in educational assessment and engineering content. Three assessments were developed: an end of module exam, a rubric for journal review, and an individual student interview protocol. Peer review of modules was accomplished numerous times throughout the development process. The four professors were available throughout the sessions for consultation on engineering content, science pedagogy, and educational technology.

The cognitive processes involved in engineering design include contextualizing, clarifying, inquiring, planning, building, testing, modifying, interpreting, and reflecting. These process skills do not occur within engineering design in any kind of linear pattern, but rather the learner employs these skills on demand in a single or layered configuration, depending upon the challenges met during the design process. Teachers were trained in the design process skills and included them as teaching strategies within the TLM.

Triangulated Learning Model

A study of current literature and best practices led to the development of the Triangulated Learning Model (TLM), a major component of the TIES project. The TLM is supported by both classroom and Web-based environments for learning the engineering design process. The model employs three major components designed to reinforce student learning: Simulation, Construction, and Connections. Student learning begins with an engaging, teacher-facilitated class discussion that introduces students to the science content necessary to begin the engineering project. Students then go to the web to experience a java applet simulation of the system of variables in the design project. Throughout the simulation, students are required to collect and analyze data and interpret the results. Using hands-on materials, students then construct a prototype of their selected project and experience first-hand the iterative engineering design process. Through reflection and discussion with other students and through large group discussions, they make sense of their learning and connect the construction process to the underlying scientific and mathematical theory and equations. They post their learning on the Connections page where other students and the teachers may comment and ask questions. The desired result is a deep conceptual and applied understanding of the topics.

Web Page Components

Flick and Bell[23] suggest five guidelines for using technology in science teaching:

1. Technology should be introduced in the context of science content.
2. Technology should address worthwhile science with appropriate pedagogy.
3. Technology instruction in science should take advantage of the unique features of technology.
4. Technology should make scientific views more accessible.
5. Technology instruction should develop students' understanding of the relationship between technology and science.

Utilizing the unique features of the web to increase students' understanding of conceptual relationships in science is a primary focus of the Triangulated Learning Model. We believe that students will experience the benefit of all five of the above guidelines as they progress through the engineering design modules developed by their teachers.

The Web page is user friendly, attractive to middle school students, and contains five major components:

1. Home Base—The opening page where students log on and select their class module
2. Simulation Page—Contains the java applet designed for a specific module
3. Data Page—Allows students to enter data from simulations and select various graphs for data representation
4. Connection Page—Students show they are making connections to prior knowledge and learning new knowledge. They post their ideas and understandings for questions and comments by peers and teachers.
5. Resource Page—Each module will display a list of Web resources as extension activities

The scenario that follows describes how students will move through a module. Once the introductory learning activities facilitated by the teacher have been accomplished in the module, students will log on to the TIES Web page to begin the simulation activity using the java applets designed by their teachers. As the students enter values for the variables and set the system in motion, relationships among the variables will become apparent. Students will log their data after each iteration of the simulation on a data collection page. Once they have completed as many iterations of the simulation they need to gain an understanding of the system, they will focus on the data collection page. The data are entered in table format, then students may select to see the data displayed in any of several graphic forms to assist in the analysis. At this point, students could click on the connections page, log the results of the data analysis, and invite comments from peers and teachers. Once student think they have learned as much as they can from the simulation, they begin the construction phase of the TLM. Through as much iteration as it takes, the students will design and build their projects. It may be that they will return to the Web to enact the simulation again to clear up misconceptions or missed information. Once completed, students return to the Connections Page on the Web and report their progress, then the projects are presented to an audience of peers for review. Adjustments are made to the project as needed. A variety of culminating activities celebrate the successful completion of a module.

Student Assessment

Assessment is not identified as a separate component of the TLM because it is a critical and integral part of every aspect of the model. Current research in school-based assessment suggests that a wide variety of ongoing and embedded assessment strategies serve to provide a far more powerful body of evidence in support of student achievement than a simplistic end-of-unit pencil and paper test.[24,25] As part of the professional development course, teachers will explore a variety of advanced assessment strategies including journals, digital photography documentation, performance tasks, Web document review, student interviews, observation, and assessment of student-generated presentation software projects. These strategies and others will be used by the teachers to collect data on student achievement and level of understanding throughout all learning activities. The current stance in educational assessment is that good learning and good assessment are often indistinguishable. [24]

Teacher Progress

About half the teacher participants are K-8 certified and the other half hold secondary certifications in science. The engineering content presented by the two professors from engineering was challenging to several of the teachers. It was gratifying to see how much persistence all the teachers had as they grappled with difficult content until they understood. Another struggle all the teachers had was attempting to come up with a suitable topic for the engineering project within the modules. Most science at the secondary level is taught as pure rather than applied, so it was difficult at first for the teachers to adjust their mind set to come up with a suitable engineering project that fit with the science standards for which they are accountable. One group thought they were on the right track as they began developing their module on inertia and friction relative to movement of air, earth and water. The engineering professors had to redirect their thinking to include a component that required students to design and build something as part of the module. The teachers also displayed great creativity in devising methods for simplifying difficult content for their students. In a discussion on vectors, the teachers informed the instructors that vectors are not taught until the more advanced high school math classes. Knowing the concept of vectors was critical to the development of their module on car-building, one teacher responded that the idea of vectors could be explained to middle school students as car + wind = changed direction of car motion.

Through our observation and experience with these eight teachers, it is clear that they are developing a greater depth of content knowledge in engineering design concepts and gaining experience in applying familiar science content to the engineering process. We look forward to the successful completion of three engineering teaching modules and more importantly, we anticipate with excitement the possibility of igniting children's increased interest in the enterprise of engineering through the dissemination of these modules.

Note: The expanded paper that will be distributed at the conference will include results of the first year data analysis including student achievement. It will also include the URL for our Web-page, which is nearing completion.

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