Engineering as Context for K-12 Science, Mathematics, and Technology Education

Lawrence J. Genalo
Iowa State University

Abstract:

One way to provide powerful problem-solving experiences in science, mathematics, and technology is to engage students in novel problems that require them to assess a situation and then apply conceptual and procedural knowledge to its solution. Engineering offers an effective context for these problem situations. However, most practicing teachers do not have the knowledge or experience to create meaningful, engineering-based learning experiences. This paper will provide details about a program to enhance the ability of preservice and inservice teachers to make these engineering experiences possible for their future or current K-12 students. Providing teachers the training necessary to make use of such engineering contexts is crucial to the success of curricular improvement.

An undergraduate engineering course has been offered for several years that began as an "engineering literacy" course and has developed into the basis for providing meaningful engineering contexts for national standards-based lessons. A graduate level engineering course for inservice teachers during the past three summers has not only provided similar training, but has also helped develop mentoring field experiences among the preservice and inservice teachers. In addition, freshmen Honors Program students take a research mentorship course in the spring of their first year. A group of Honors engineering and science majors are working to create K-12 activities based on engineering context. They are working with the education majors in the course previously mentioned in order to create standards-based, age-appropriate activities. Engineering and education faculty and students, working in teams, through the courses mentioned and the mentorship program, have developed activities that bring authentic learning in engineering contexts to science, mathematics, and technology education. Examples of such standards-based activities will be provided.

Introduction:

"At the heart of our modern technological society lies an unacknowledged paradox. Although the United States is increasingly defined by and dependent on technology and is adopting new technologies at a breathtaking pace, its citizens are not equipped to make well-considered decisions or to think critically about technology. As a society, we are not even fully aware of, or conversant with, the technologies we use every day. In short, we are not 'technologically literate.'"[1] Now more than ever, the United States needs a skilled, technologically literate workforce whose members can address problems with time-tested solutions as well as creative problem solving. Increasing the pool of workers with strong problem-solving skills requires that K-12 students have experiences in quality science, mathematics, and technology problem-solving environments. The teaching and learning of science should be centered on inquiry-based strategies that incorporate real world experiences. "From the very first day in school students should do science…not study science."[2] Such strategies include the development of science inquiry skills, scientific habits of mind, and communication skills for dealing with the community at large.[3]

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Similarly, in mathematics, "In effective teaching, worthwhile mathematical tasks are used to introduce important mathematical ideas and to engage and challenge students intellectually. Well-chosen tasks can pique students' curiosity and draw them into mathematics. The tasks may be connected to the real-world experiences of students, or they may arise in contexts that are purely mathematical."[4] Clearly, problem solving is the crux of quality mathematics learning and teaching.

One way to provide powerful problem-solving experiences in science, mathematics, and technology is to engage students in novel problems that require them to assess a situation and then apply conceptual and procedural knowledge to its solution.[5-7] Engineering offers an effective context for these problem situations. However, most practicing teachers do not have the knowledge or experience to create meaningful, engineering-based learning experiences. A collaborative effort between the colleges of engineering and education at Iowa State University is enhancing the ability of preservice and inservice teachers to make these engineering experiences possible for their future or current K-12 students. Providing teachers the training necessary to make use of such engineering contexts is crucial to the success of curricular improvement.[8]

The time is right for centering attention on developing well-qualified K-12 teachers with strong backgrounds in engineering. In the next decade alone, our nation's schools will need to hire 2.2 million teachers.[9] The need will be greatest in rural and urban schools.[10] There are roughly 40,000 technology education teachers in the United States and most of them are in secondary schools.[11,12] There are, however, almost 1.7 million elementary level teachers responsible for teaching science.[13] National models to improve elementary education teacher preparedness and increase the number of persons entering the teaching profession are needed.

The growing demand for knowledgeable, effective K-12 science, mathematics, and technology teachers coincides with industry's continuing demand for well-trained engineers. Despite a growing, critical need for engineers, "the number of bachelor's degrees awarded in engineering began declining in 1987 and has continued to stay at about the same level through much of the 1990s. The total number of graduates from engineering programs is not expected to increase significantly over the projection period."[14] In the year 2000 an estimated 400,000 engineering jobs were unfilled; projections indicate that number will grow to 1.75 million by 2008.[15] In recognition of this growing problem, the American Society for Engineering Education has a web site for K-12 SMET education that can be viewed at www.asee.org/K-12smet_ed/.

Taken together these projections suggest a strong need for high quality, standards-based science, mathematics, and technology learning environments for K-12 students. Engineering contexts for science, mathematics, and technology learning in K-12 schools can make the learning more meaningful. This paper discusses a project to create and implement such contexts and presents an example of such an engineering context taken from an "engineering literacy" course for preservice teachers at Iowa State University.

The Toying With Technology[SM] Program:

A program at Iowa State has entered the arena of K-12 engineering education by using engineering-based contexts to provide authentic learning environments for K-12 students and pre and inservice teachers. An undergraduate engineering course has been offered for several years at Iowa State University. It began as an "engineering literacy" course[16-18] and has developed into the basis for providing meaningful engineering contexts for national standards-based lessons. A graduate level engineering course[19] for inservice teachers during the past three summers has not only provided similar training but has also helped develop mentoring field experiences among the preservice and inservice teachers.

In addition, freshmen Honors Program students take a research mentorship course in the spring of their first year. A group of Honors engineering and science majors are working to create K-12 activities based on engineering context. They are working with the education majors in the course previously mentioned in order to create standards-based, age-appropriate activities. Engineering and education faculty and students, working in teams through the courses mentioned and the mentorship program, have developed activities that bring authentic learning in engineering contexts to science, mathematics, and technology education.

The highly successful Toying With Technology[SM] (TWT) Program at Iowa State[16-19] is a model for bringing engineering context to standards-based K-12 science, mathematics, and technology curricula and to relate this work to teacher education. The program includes teacher education courses at the undergraduate and graduate levels (offered in the summer to accommodate inservice teachers), workshops for teachers and faculty, and experiential classroom partnerships with K-12 schools. An engineering faculty member, a teacher education Ph.D. student, and undergraduate students in engineering and education form the management and operations team for this program. With guidance from the Ph.D. student's teacher education faculty advisor, this team researches existing engineering context and creates new context for K-12 lessons in robotics that help to meet national standards. These new curricular materials are employed in the TWT courses and tested by preservice teachers in the experiential K-12 learning environments by partner schools. Existing engineering materials, such as those developed by Seymour Papert at MIT,[20] Ellen Frye at Dartmouth,[21] Martha Cyr at Tufts,[22] and Richard Drushel at Case Western,[23] to name just a few, are adapted for use in the TWT Program and its partner schools. Other materials that are developed are based on constructivist principles espoused by Papert.[24]

The following example shows how engineering context can be used to meet national standards. Since engineering is an integrative discipline, many different national standards can be addressed and various grade levels targeted by the same engineering experience. Beginning with national standards for science (NSES)[3], mathematics (NCTM)[4], and technology (STL)[25] education, an engineering experience in robotics using LEGO® Mindstorms® kits was developed. Posed as a design and problem solving experience using familiar building materials, 4th – 6th grade students learn through constructivist, hands-on practices.

The lesson begins by posing an engineering "real-world" problem for the students to solve. "NASA is designing an autonomous, robotic 'buggy' to be used to investigate the surface of the moon. This will require the robot to be programmed to move in precise patterns to navigate about the moon." This project will last for a month, utilize four hours per week of classroom time, and be facilitated by preservice teachers and undergraduate engineering students under the guidance of teacher education and engineering graduate students and faculty. It will culminate in presentations of their design by the 4th – 6th grade students.

The lessons shown here, the first week or four hours of class time, are the first in the series that builds the students' problem-solving skills toward being able to design and build the robot. Design and problem solving, the essence of engineering, are also prominently mentioned in science, mathematics, and technology education standards. These lessons require students, working in teams of two, to build a two-motor (independent drive for the left and right rear wheels) robotic buggy and learn to program its controller to perform simple directional maneuvers. The students build a prescribed buggy (they will later design their own) and are given a basic program, written in a version of C called "Not Quite C,"[26] and are shown how to compile and download the program to their autonomous robot. The program instructs the buggy to move forward for five seconds, wait one second, and move backward for five seconds. Student teams are then challenged with a series of problem-solving tasks that have been designed to help students reach the standards. They are asked to alter the given program to make the buggy go forward a specified distance; then to make the buggy go the specified distance and turn 90°; make it drive in a complete square; employ a bump sensor to avoid walls; and employ a light (reflective) sensor to follow a black line on a white surface. Each challenge has been aligned with national standards (see Table 1) and tested in preservice teacher education courses and with 4th – 6th grade students. All involved parties assess the learning so that modifications for increased efficacy can be made. A significant portion of each TWT undergraduate course is a month-long experiential learning project in a partner school classroom such as the one described.

Table 1: National Standards and Engineering Context

Standards		Engineering Context Activity											
Standards Used	Domain/topic/benchmark	build prescribed buggy	download given program	run buggy	drive specified distance	distance + turn right angle	drive in a square	add bump sensor to buggy	download bump program	alter when bump avoid/go	add light sensor	download light program	alter to follow black line
NSES	A. science as inquiry (K-4, 5-8) · abilities necessary to do scientific inquiry				X	X	X			X			X
NSES	B. physical science · position and motion of objects (K-4) · motions and forces (5-8)				X	X	X			X			X
NSES	E. science and technology (K-4, 5-8) · abilities of technological design	X	X	X	X	X	X	X	X	X	X	X	X
NCTM	problem solving · solve problems in math and other contexts				X	X	X			X			X
NCTM	problem solving · apply/adapt a variety of appropriate strategies				X	X	X			X			X
STL	2. core concepts of technology · systems, requirements, processes (3-5, 6-8) · controls (6-8)	X	X	X	X	X	X	X	X	X	X	X	X
STL	9. engineering design · creativity (3-5)				X	X	X			X			X
STL	9. engineering design · testing, evaluating, modifying (6-8)			X	X	X	X			X			X
STL	10. troubleshooting, innovation, experimentation · troubleshoot, innovate, experiment (3-5, 6-8)			X	X	X	X			X			X
STL	12. tech products and systems ·step-by-step instructions (3-5) ·use computers (3-5, 6-8)	X	X	X	X	X	X		X	X		X	X
STL	12. tech products and systems ·operate systems (6-8)			X	X	X	X			X			X

The teacher education graduate student working on the TWT prototype team is doing research in the area of engineering content in a constructivist-learning environment and its effect on learning for preservice teachers.[16,19] The engineering students working on this team become sensitized to issues of and involved in assisting K-12 education. They have organized and directed the FIRST LEGO® League robotics competition for the State of Iowa,[27] written and presented papers at national conferences,[16-18,27] and created software so that students with reading difficulties could participate in TWT. This software was piloted in a magnet school in

Des Moines and expanded at the Iowa School for the Deaf.

Distance education delivery systems and the establishment of virtual learning communities will expand the horizon for these lessons to a national audience. A program has been piloted in a Burlington, Iowa first grade class that brings together engineering faculty and students at a distance, elementary teachers and their students, and practicing engineers in the school's area, to facilitate engineering robotics lessons in the schools.

The Freshman Honors Program:

Freshmen in the Honors Program at Iowa State University can choose to take a research mentorship course in the spring of their first year. The student signs up for a mentorship based on their interests and faculty volunteer to be mentors and also state the area of their research interests. The students and faculty are then matched by common interests and the student participates with the faculty member's research group. Eleven Honors engineering and science majors are working (spring semester, 2003) to create K-12 activities based on engineering context. They are working with the education majors in the course previously mentioned in order to create standards-based, age-appropriate activities. Engineering and education faculty and students, working in teams, through the courses mentioned and the mentorship program, are developing activities that bring authentic learning in engineering contexts to science, mathematics, and technology education. Our ultimate goal is to see engineering infused throughout the K-12 curriculum as is being done in Massachusetts.[28]

Conclusion

There are severe shortfalls in the engineering workforce and, at the same time, the number of K-12 teachers proficient in science, mathematics, and technology topics is extremely low. This shortage of teachers able to create and deliver STEM-based lessons is felt especially in the lower grades where teachers are asked to be content experts in all fields. Providing these teachers with classroom-ready, engineering context-based, activities aligned with national standards will help them to improve the science, mathematics, and technology proficiencies of their students. Their students, feeling more able to solve problems in STEM fields, will be more likely to choose engineering as a career in greater numbers. Those students who choose to become K-12 teachers will be more able to introduce STEM topics to their students. Even those who choose not to go into STEM-related careers or teaching will be more informed citizens.

The program presented here is helping to increase the numbers of teachers who are able to operate in engineering related contexts. Each semester 20 to 30 preservice teachers complete a three-credit engineering course. Each summer 20 to 30 inservice teachers complete a two-credit graduate engineering course. Each year, numerous K-12 outreach events provide field experience for preservice teachers, link pre and inservice teachers, and reach thousands of K-12 students.

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Biography:

LAWRENCE J. GENALO is Professor and Assistant Chair of the Department of Materials Science and Engineering at Iowa State University. He received a Ph. D. in Applied Mathematics with Systems Engineering emphasis in 1977, served as Chair for Freshman Programs and DELOS Divisions, and runs the Toying With Technology[SM] Program at Iowa State.