01 Jan 2003

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Theresa M. Swift
Missouri University of Science and Technology, thswift@mst.edu

Steve Eugene Watkins
Missouri University of Science and Technology, watkins@mst.edu

Kristine Swenson
Missouri University of Science and Technology, kswenson@mst.edu

Evalee Lasater

et. al. For a complete list of authors, see https://scholarsmine.mst.edu/ele_comeng_facwork/69

Recommended Citation

T. M. Swift et al., "Involving Engineering with In-Service K-4 Teachers," *Proceedings of the 2003 ASEE Annual Conference and Exposition: Staying in Tune with Engineering Education*, pp. 10601-10612, American Society for Engineering Education (ASEE), Jan 2003.

Involving Engineering with In-Service K-4 Teachers

Theresa M. Swift, Steve E. Watkins, Kristine Swenson,
EvaLee Lasater, Robert Mitchell

University of Missouri-Rolla

Abstract

A strong workforce in science and engineering and literate citizens in a technology-based society depends on an educational system that prepares students in science, mathematics, and engineering. Unfortunately, many K-12 students lose interest in such topics early in their school years. Engineering applications can capture the imagination of students and illustrate the concepts in science and mathematics. Level-appropriate resources are as necessary for primary teachers and our young scholars as for teachers and students in higher grades.

A model for interaction between engineers and K-4 teachers is proposed. The State of Missouri defines curriculum standards in each subject area and assesses student performance three times during a student's education. The first assessment for science is in the third grade and for mathematics is in the fourth grade. These standards were examined from an engineering perspective. In addition, in-service primary teachers were surveyed to determine their background, needs, and attitudes regarding science, mathematics, and engineering. Early years of an effective technical curriculum must introduce the basic concepts and begin layering this understanding with detail and connectivity. Our model shows how engineering applications can provide hearing, seeing, and doing components, i.e. auditory, visual, and kinesthetic educational activities, within the recommended pedagogy. The approach involves in-service teachers throughout the development process, addresses state standards and testing criteria, and partners specialists in engineering content and teacher training.

I. Introduction

The long-term health of our scientific and engineering infrastructure and the effective functioning of citizens in a technology-based society depend on an educational system that prepares students to be technically literate. They should understand concepts in science and mathematics and applications in engineering. Unfortunately, many K-12 students lose interest and motivation in science, mathematics, and technology early in their school years. Consequently, technical programs and resources targeted at high school and, to some extent, middle school students are too late in the educational process for some students.

Curriculum standards in science and mathematics are defined at various levels of K-12 education. The early technical content provides the foundation for later advanced concepts. Thus, the performance and motivation in higher grades are handicapped without effective content in the primary grades and technical training for primary teachers. Attention has been focused on preparing pre-service teachers for teaching science through engineering.[1-4] However, attention also must be directed to the teachers already in the classrooms across the nation. Interaction between university-level faculty and in-service K-12 teachers has been facilitated by the use of LEGOS[4,5,6] and extracurricular camps.[7,8] While some papers indicated success with children as young as three years of age, the focus still seemed to be on the middle-school, or older, student. Engineering deans nationwide are very aware of the need to improve the K-12 pipeline and, recently, they have been working as a group to help provide solutions. They are willing to reward those faculty who make significant steps in this direction. The President's "No Child Left Behind" initiative and the complementary Math and Science Partnership (MSP) programs at the National Science Foundation and the Department of Education are creating incentives for research and development that fit within the traditional faculty reward structure.

This paper describes the working collaboration of faculty and students from the University of Missouri-Rolla (UMR) and in-service K-4 teachers from three area schools. Our focus areas were to address the mandated criteria for student assessment and to incorporate the expertise of in-service teachers. The state standards for science and mathematics education were examined and compared to the curriculums of local schools. The teachers were surveyed as to their background training for teaching science and mathematics, their attitudes toward teaching science and mathematics, their perception of their students' attitudes toward science and mathematics, and the availability of teaching resources for science and mathematics. Survey results and teacher comments are included. A model for successful collaboration is discussed.

II. K-4 Science Content and Testing in Missouri

The State of Missouri has put forth the Show Me Standards[9], based on national standards, which defines the recommended education curriculum in its schools including the subjects of science and mathematics. The Missouri Department of Elementary and Secondary Education constructed a framework for curriculum development in K-12 science and mathematics.[9] It divides the science and mathematics curricula into several categories:

- Science I – Scientific Inquiry (Processes and Investigations), Scientific Relevance (The Nature of Technology, Historical Perspective, and Science as a Human Endeavor), Matter and Energy (Characteristics, Forms, & Sources of Energy, Characteristics, Forms, & Sources of Matter, and Interactions of Matter and Energy) and Force, Motion, & Mechanical Energy (Relative Motion, Types and Properties, and Interactions)
- Science II – Universe (Solar System and Tools of Exploration), Earth Systems (Physical Systems and Processes of Systems), Living Systems (Structures, Life Processes, Diversity, Reproduction, and Adaptation), and Ecology (Interactions and Changes)
- Mathematics – Problem Solving, Communication, Reasoning, Connections, Number Sense, Geometric and Spatial Sense, Data Analysis (Probability and Statistics), Patterns and Relationships, Mathematical Systems and Number Theory, and Discrete Mathematics.

Each section has its own list of "What all students should know" and "What all students should be able to do." Sample learning activities are included in each section and categorized by grade level. Engineering topics are included, but are not typically labeled as such.

For instance, consider "Properties, Characteristics and Structures of Matter" within the "Matter and Energy" subcategory. The Framework for Curriculum Development, based on the Show Me Standards, states the three concepts that students by the end of the fourth grade should know and the associated things they should be able to do.[9] These are summarized in Table 1. Note that the abilities to make measurements and to use related tools are included.

Student assessment is through the Missouri Assessment Program[9] (MAP) which is based on the Show Me Standards and the Framework for Curriculum Development. Science is tested at the third, seventh, and tenth grade levels. Mathematics topics are tested at the fourth, eighth, and tenth grade levels. Significant drops in the percentage of students testing at the "proficient" level or higher in science can be seen as they progress through the grade levels. Results are available for 1998 through 2002.[9] Looking at the MAP results for the entire state from 2002, 47.7% of third graders scored at the "proficient" level or higher. This compares to 14.2% of seventh graders and 5.2% of tenth graders scoring at the same level that year. This same pattern can be seen in sequential MAP testing of the same group of students. In 1998, 38.8% of third graders tested at the "proficient" level or higher. In 2002, as seventh graders, only 14.2% tested at the "proficient" or higher level.[9] The results for mathematics are similar, but with less severe drops in performance.

This dramatic decrease may be, at least partially, a result of students losing interest in science at an early age. Opportunities to increase interest in science and provide a sense of continuity and everyday relevance for the students should be explored. Lower grades focus on constructing a foundation. Thus, mathematical skills and basic scientific facts receive more emphasis than higher-level concepts. However, third-grade students are assessed in science via the MAP and critical thinking skills are required. Thus, the transition from foundational to higher-level thinking must be accomplished at an early age. Engineering seems to be a logical choice since it is an application of science and mathematics and could be used both in the learning of fundamental concepts and applying the critical thinking required to understand more advanced ideas and connect concepts.

Table 1: Conceptual Framework Based on the Show Me Standards for Properties, Characteristics and Structures of Matter in Fourth Grade

What All Students Should Know	What All Students Should Be Able To Do
1. Matter is anything that has mass and volume and is composed of smaller parts.	a. select and classify a variety of common materials and objects as being composed of one substance or more than one substance b. refine and adapt the parts of objects to create a new object c. demonstrate the mass of an object equals the sum of the masses of its parts.
2. Substances can occur either in pure form or as a mixture.	a. predict the properties of a mixture given the concentration of ingredients b. identify the factors that determine the choice of materials for a particular purpose
3. Physical properties of matter can change.	a. use magnifiers, measuring tools, and other technology to identify the properties of matter or objects b. select and apply strategies to change matter by heating or cooling predict what changes will occur

The partner schools for our work are Dent-Phelps R-3, Salem R-80, and St. James R-1. All are in a thirty-mile radius of the University of Missouri-Rolla. They are Missouri School Improvement Plan (MSIP) accredited by the Missouri Department of Elementary and Secondary Education and are classified as rural public schools. The Dent-Phelps school offers K-8 instruction with two teachers per primary grade level. Overall, it has about 300 students and thirty certified teachers. The Salem school offers K-12 instruction with four or five teachers per primary grade level. Overall, it has 1,582 students and 148 certified teachers. The St. James school offers K-12 instruction with five or six teacher per primary grade level. Overall, it has 1,841 students and 156 certified teachers. Detailed information about the schools is available through the Missouri Department of Elementary and Secondary Education.[9]

The schools take the state standards and develop their own curriculum based on those standards. Consider an example of how the schools interpret these state standards for item 3a and b in Table 1 from the Dent-Phelps school curriculum. Fourth grade students at Dent-Phelps must be able differentiate forms of matter by meeting the following requirements:

- Measure length, volume, mass and weight using appropriate instruments and record the data,
- Identify the three states of matter and describe the three characteristics of each,
- Measure the temperature at which matter changes from on state to another and recognize the variables that affect the changes,

Curriculum information gathered from teachers and administrators in all the partner schools was similar.

III. In-Service Teacher Survey

A survey covering teachers' background training for teaching science, their attitudes toward teaching science, their perception of their students' attitudes toward science and mathematics, and the availability of teaching resources was given to local primary teachers and administrators in late 2002. A total of 22 teachers responded, eight from Salem, seven from Dent-Phelps, six from St. James, and one from Waynesville (another school in the area) though not all teachers responded to every question. Results for the 13 survey questions are summarized in Figures 1 and 2 and Table 2.

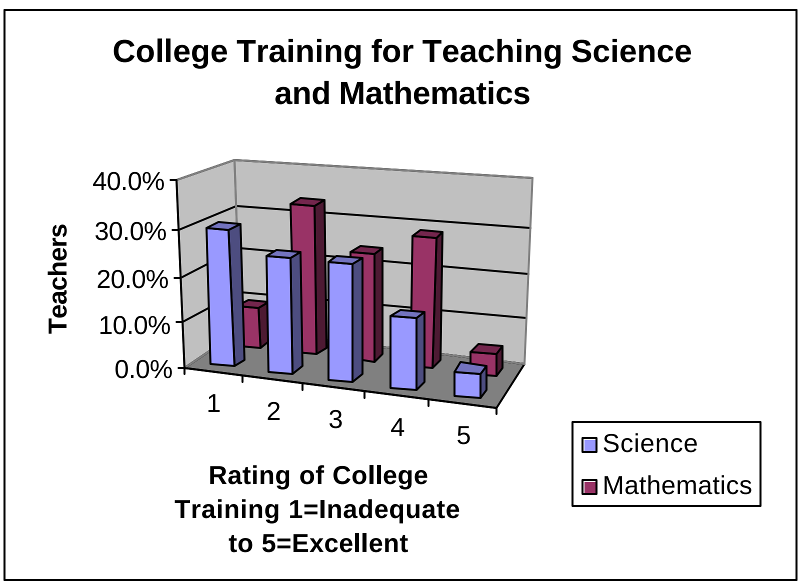

Figure 1: Rating of Formal College Training for Teaching Science and Mathematics

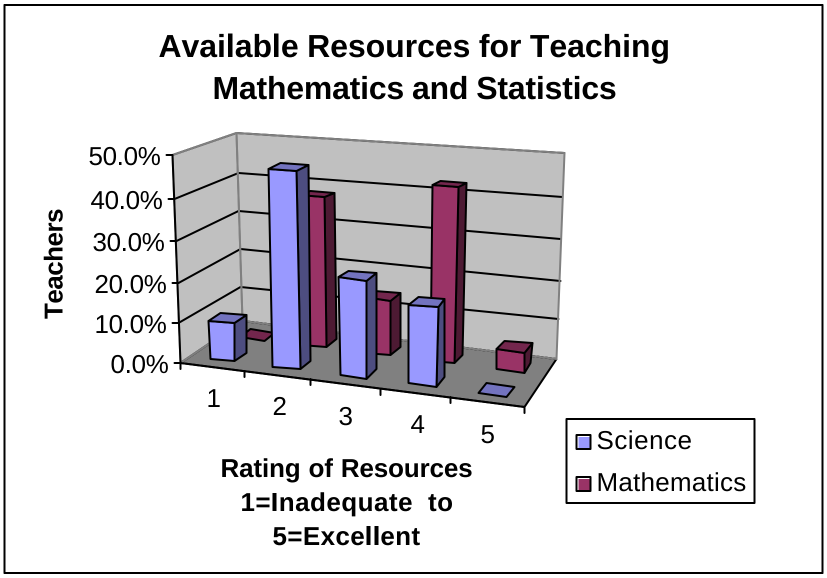

Figure 2: Rating of the Available Resources for Teaching Mathematics and Statistics

Also included, were questions which asked the teachers to rate the difficulty level of teaching ten areas of mathematics and science, summarized in Table 3, and open questions where teachers were asked to discuss how they teach science in their classrooms. Some salient comments are listed below.

- ***Do you like teaching science and mathematics topics? Please describe.***
  "Yes, both of these can be made fun by more hands-on manipulatives and by using examples that my students can relate to daily life,"
  "I like teaching math more than science because I see more success with math and I can see improvement. I have to force myself to teach science," and
  "I used to until MAP limited what I can teach,"
- ***How are science and mathematics related in your classes?***
  "Math is integrated in science by graphs, charts, measuring, estimation, etc." and
  "I need help pulling the two together."
- ***Do you include engineering topics in your teaching of science and mathematics? Please describe.***
  "Not at my grade level – too confusing!"
  "No, not at third grade level,"
  "I teach simple machines and have student build a trap for a Performance Task (with their parents)," and
  "I haven't but would like to."

- ***How do you teach science and mathematics concepts? What works and does not work?***
  "Hands-on activities work the best," and
  "Math and science concepts are easier to understand when you can apply to real life,"
- ***What resources could UMR provide that would help you teach science and mathematics?***
  "More science resources - books, websites, seminars – that address science concepts at a young level. Most resources available now are 'over their heads',"
  "I would like to take classes or workshops to learn activities & concepts to teach about how fun math and science can be," and
  "Models that would help students see concepts in action."

- ***What are the strengths and weaknesses of the MAP for science and mathematics?***
  "Vocabulary weaknesses (or differences) get in the way of what they really know. Too many objectives are tested compared with the time available to teach,"
  "Subject matter too high for third grade, the topics change each year making it difficult to prepare for the test,"

In general, the teachers stated that they like teaching science and mathematics but felt that their formal college training had not prepared them well for the task. They also indicated that the availability of resources for teaching science is a problem with 57% of surveyed teachers ranking their availability of science resources as "adequate" or below. The background, resources, and performance for mathematics were rated higher than for science.

The open question concerning the incorporation of engineering topics had a range of answers. Some recognized the value of engineering examples. Others felt that engineering content was too advanced. However, all teachers indicated in other questions that additional resources and training for science and mathematics would be welcome.

Two brainstorming sessions were also held in which in-service teachers from the participating area schools were asked for specific content areas where they felt that their science and mathematics teaching resources could be improved. The primary focus was on the areas of matter and energy, scientific inquiry, scientific relevance, and force and motion though other areas of science and mathematics were also discussed. They were asked: If you could have anything you wanted to teach science in your classroom, what would it be?

A common theme presented by the teachers at both sessions was the idea of continuity. They were particularly interested in resources that could be easily adapted to different age levels. Each grade level could add additional modules, so, as students

Table 2: Results of Teacher Survey (Selections for Each Choice Are Given).

	0-5%	5-10%	10-25%	>25%
How much time do you spend on science in your class (teachers) or does your K-4 curriculum spend on science topics (administrators)?	0	10	8	2
How much time do you spend on mathematics in your class (teachers) or does your K-4 curriculum spend on mathematics topics (administrators)?	0	2	13	5

	Less Well	Same	Better
Relative to other topics in the class or curriculum, how do your students perform in science?	4	16	1
Relative to other topics in the class or curriculum, how do your students perform in mathematics?	4	12	5

	Inadequate	Adequate	Moderate	Very Good	Excellent
How do you rate your formal college training for teaching science?	6	5	5	3	1
How do you rate your formal college training for teaching mathematics?	2	7	5	6	1
How do you rate your available resources for teaching science?	2	10	5	4	0
How do you rate your available resources for teaching mathematics?	0	8	3	9	1

	Yes	No	No difference from other topics
Do you consider science a problem area for your students?	4	7	10
Do you consider mathematics a problem area for your students?	7	8	5
Relative to other topics in the curriculum, do your students consider science difficult?	7	7	6
Relative to other topics in the curriculum, do your students consider mathematics difficult?	5	11	4

	Very Little	Somewhat	Very Much
Do you consider the MAP test results an accurate reflection of student ability?	7	9	1

Table 3: Survey Results for the Difficulty Level in Teaching Subjects

Rate the Difficulty Level in Teaching the Following Areas (1 – Little Difficulty to 5 – Much Difficulty)			
	Mean Rating		Mean Rating
Scientific Inquiry	3.9	Scientific Relevance	3.6
Matter & Energy	3.4	Force, Motion, & Mechanical Energy	3.1
Universe	2.2	Earth Systems	2.4
Living Systems	1.8	Ecology	2.1
Mathematics	1.9	Computers	2.2

progressed through the grades, they would experience continuity in scientific learning. Modules should incorporate auditory, visual, and kinesthetic components to fulfill the "tell, show, and do" portions of the recommended primary grade pedagogy.

IV. Proposed Model for Interaction between Engineers and K-4 Teachers

Any workable model for interaction between engineers and K-4 teachers must first of all involve the teachers. It is the in-service K-4 teachers who are the experts on their pupils. An interdisciplinary team is also critical. Experts in engineering, English, and education and teacher training are needed to form a well-rounded team. Engineering specialists will provide the technical components. The teacher training specialists and the in-service teachers will be responsible for determining level-appropriate content and are the experts on how primary students learn. The technical communication experts in English will serve as the bridge between engineering and education. Finally, as it is the method by which students are evaluated, the topics covered by the MAP must be addressed.

Engineering applications can be tailored to fit into the K-4 curriculum. They can provide the student with a practical "hands-on" vision of science and mathematics. Engineering can give direct examples for the scientific relevance category and can support the other standards especially with regard to the ability to make measurements and to use tools. Teachers are often limited to what they themselves can build in order to demonstrate technical concepts in their classrooms. By working with engineers, the boundaries can be extended giving the teachers more flexibility in designing their curriculum.

Faculty from any engineering discipline could be involved. For example, the Curriculum Frameworks requires that fourth-grade students know that “electricity can be converted into light, heat, sound, magnetism, or mechanical motion”[9] and that students be able to apply knowledge of simple circuits to create a new circuit that involves more components.”[9] An electrical engineering faculty member could be involved in the development of a safe, cost-effective apparatus to demonstrate this concept that would allow the students to get their hands on a physical circuit and also provide teachers with background material so that they can adequately answer questions posed by their students. Professional societies and engineering schools often encourage their members to be involved in pre-college outreach activities and reward them accordingly.

V. Summary

Missouri state standards for science and mathematics, as detailed in the Show Me Standards, were compared to the science and mathematics curricula for the local schools. The Show Me Standards divide the science and mathematics curriculum into several categories: scientific inquiry; scientific relevance; matter and energy; force, motion, and mechanical energy; the universe; earth systems; living systems, ecology, and mathematics. Teachers indicated that scientific inquiry and scientific relevance were the most difficult for them to teach. Student performance in science and mathematics falls markedly during their K-12 education.

Faculty and students from the University of Missouri-Rolla worked with in-service K-4 teachers from three area schools: Dent-Phelps R-3, Salem R-80, and St. James R-1. The goals were to establish a dialog with teachers and to define characteristics of appropriate engineering resources. A common flaw in many interactions between engineers and elementary education is that the testing objectives are not addressed. A demonstration that is “neat” might not provide foundational or critical thinking skills required in the testing procedures used by the state. The contributions of this paper are to determine in-service teacher attitudes toward engineering concepts, compare these engineering concepts with testing objectives, and to define an appropriate team structure to facilitate effective interaction. As a result of this dialog with the in-service teachers, several projects aimed specifically at the K-4 age group are currently underway. Results are pending.

There was a noticeable difference between teacher responses for science versus mathematics. On average, teachers spent more time on mathematics than science in their curriculum. There were mixed responses from the teachers when asked how the topics were related in their classroom. Some treated mathematics and science as two separate subjects while others sought to integrate them. Teachers tended to rate their formal training and available resources for teaching science lower than for mathematics. They expressed interest in resources that could be used throughout the K-4 curriculum to provide their students with a sense of continuity in their science education.

Engineering applications lend themselves naturally to the topics covered in the Show Me Standards, especially the scientific relevance category, and can provide a wealth of resources for teachers to enrich their curriculum. The challenges at the lower grades are to make the resources age-appropriate, to provide a continuity of instruction through grade levels, and to incorporate auditory, visual, and kinesthetic elements. The approach must involve in-service teachers throughout the development process, must address state standards and testing criteria, and must partner specialists in engineering content and teacher training.

Acknowledgements

This work was supported by the National Science Foundation through the Bridges for Engineering Education Grant # EEC-0230705. The participation of teachers and administrators from the Dent-Phelps R-3, Salem R-80, and St. James R-1 Schools is gratefully acknowledged.

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THERESA M. SWIFT
Theresa M. Swift is a graduate student in electrical engineering and is a graduate teaching assistant in the Department of Mathematics and Statistics at the University of Missouri-Rolla. Her interdisciplinary research project addresses the role of engineers in K-4 education. She received a M.S. in applied mathematics from the University of Missouri-Rolla in 1992.

STEVE E. WATKINS
Dr. Steve E. Watkins is Director of the Applied Optics Laboratory and Associate Professor of Electrical and Computer Engineering at the University of Missouri-Rolla. He is a member of several interdisciplinary research teams with projects addressing improvements in engineering educational and the application of fiber optic sensor systems. He received his Ph.D. from the University of Texas at Austin in 1989.

KRISTINE SWENSON
Dr. Kristine Swenson is an Assistant Professor of English at the University of Missouri-Rolla. Her technical interests include literature and science, technical communication, and technologies of gender. She received a Ph.D. in English Language and Literature from the University of Iowa in 1995.

EVALEE LASATER
Dr. EveLee Lasater is Education Program Coordinator and Adjunct Assistant Professor of Education at the University of Missouri-Rolla. Her research interests include media for the pre-college classroom. She received her Ed.D. from the California Coast University in 1983.

O. ROBERT MITCHELL
Dr. O. Robert Mitchell is Dean for the School of Engineering and Professor of Electrical and Computer Engineering at the University of Missouri-Rolla. He conducts research in the application of intelligent computer vision systems. He received his Ph.D. from the Massachusetts Institute of Technology in 1972.