INTRODUCING AN INTEGRATIVE APPROACH TO TEACH MIDDLE SCHOOL MATHEMATICS AND SCIENCE SUBJECTS

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Introduction

To cope with the rapid advancement in science and technology and the challenge of economic globalization, our country must have a good supply of competent engineers and scientists. However, most students from our nation's schools are not sufficiently prepared for science and mathematics subjects. As a result, many of them are not qualified to enter engineering programs. Among those who are admitted, the dropout rate is high. To search for the root of the problem, one can look at the recently released results from the Third International Mathematics and Science Study-Repeat[1]. That report showed that the U.S. 8th grade mathematics and science scores were below the international average. Even more alarming is the fact that those scores declined from 4th to 8th grade

This disappointing picture shows that a major effort must be made to implement national and state standards.[2, 3, 4] In a recent report entitled "Before It Is Too Late,"[5] the National Commission on Mathematics and Science Teaching for the 21st Century warned that time is running out for action and stated that the most urgent need is to upgrade the quality, skills, and knowledge of mathematics and science teachers. It further stated "...summer institute must be established to address the professional needs identified." In 2001, the Elementary and Secondary Education Act set new goals in the No Child Left Behind Act.

We believe that one key element in addressing the problem would be to improve middle school mathematics and science education, in particular the mathematics education. The reason is twofold. First, available statistics show that is the weakest link in American schools. Second, students' attitude towards mathematics is formed early in life and that attitude becomes fairly well established at the age of 10 to 14 during the middle school years.[6] If students lose interest in mathematics and science at this young age, it is very difficult to get them excited about these subjects in high school.

Effective teaching of mathematics and science requires that teachers possess an in-depth understanding of not only the subject content, but also connections of these two subjects with applications. However, most teachers' collegiate education experiences did not provide an adequate foundation to make these connections. An effective method to fill the need must be developed.

It is well known that science concepts are best understood in the context of practical problem solving. An exceptionally appropriate field of study to address this issue is engineering. Engineering and applied science topics would offer not only many interesting open-ended problems, but also a systematic approach to problem solving where teamwork and creativity are essential. As teachers strengthen their understanding of contents through applications and connections, they will be better equipped to develop interesting and worthwhile problems to motivate and challenge their students.

To address the needs mentioned above, we obtained a two-year Eisenhower Grant to organize summer workshops in 2001 and 2002 at the University of Wisconsin-Platteville. The focus of the program was to develop a program to address the need of middle school mathematics and science teachers, in particular those working in the rural area. The University is located in southwestern Wisconsin where most pupils in the area are living in farming communities of population less than 2,500. As stated in the monograph "Science Education in Rural America,"[7] policy initiatives are needed in rural areas because many students there do not have opportunities to participate in activities that lead to science learning.

Our team included faculty from mechanical engineering and education departments, and a master teacher from a local middle school. The responsibility of the engineering faculty was to teach the content material while that of the education faculty was to take care of the pedagogy issue. The master teacher served as a tutor and a facilitator to help teachers learn concepts and work with them in developing curriculum.

This paper provides a brief account of how we conducted the workshop to address the content issue and the experience learned from this endeavor.

Program Organization

Our program was designed to provide professional development activities in the core academic subjects of mathematics and science to middle school teachers with the goals to enhance their competency in (1) subject matter knowledge; (2) skill in computer usage; and (3) teaching techniques. Fulfillment of these goals would lead to significant improvement in middle school education of mathematics and science. The emphasis of the workshop was on teacher-curriculum development and assessment based on National and State Educational Standards.

A) Educational Approaches. We believe that guiding students in active and extended science inquiry may be fruitfully achieved through a process of group investigation to solve real-world problems. To this end our approach was centered on the use of the group instructional model in conjunction with an inquiry-based learning technique to solve selected hands-on projects. Participants worked in groups of three through the entire workshop period in learning and developing content materials for use in their classroom teaching. In addition, they were also educated and coached by the education faculty and the master teacher to learn the use of the group instructional model that had been proved to be a very effective teaching method.[8] By blending content and pedagogy into a seamless web, the workshop enabled teachers to make a difference in improving students' learning of mathematics and science.

Working with hands-on projects, participants were required to combine mathematics and science to solve problems. They were thus exposed to the integrative nature of mathematics and science and had first hand experience on how science subjects can provide interesting problems to the study of mathematics, and how mathematics can serve as a powerful tool to analyze scientific data. With this integrative approach, teachers from both fields were better equipped to develop interesting and worthwhile problems to motivate and challenge students.

B) Organization. The workshop was implemented over two consecutive summers in 2001 and 2002 at the University of Wisconsin-Platteville. Each workshop lasted for three weeks and each week consisted of four days of intense learning activities. Each day the activity was divided into two sessions, the morning session to address the content issue and the afternoon one to address the pedagogy issue. Each session lasted for four hours.

In the morning session, activities consisted of lectures, laboratory work, and group discussions. Activities in the afternoon session were to complement the work covered in the morning session with emphasis on instructional design, delivery, and evaluation and with special attention to reading in the content areas. Teachers studied the group investigation and other models of teaching for implementation in their classrooms. Coaching in the models took place in the summer institute and during the school year.

C) Preparatory Work. To make the program more effective, we conducted an initial survey of participants' needs and interests prior to the workshop. Based on the results of the survey, we finalized our education plan. The following six areas were emphasized in our curriculum: (a) probability and statistics, (b) force, motion, and science of sports, (c) simple machines, (d) physics of human activities, (e) renewable energy, and (f) computer skills. These areas were selected not only because they covered a broad range of subjects identified by the workshop participants, but also because they are useful to show the interplay between mathematics and various branches of science. These subjects were covered in the two summer sessions.

Through our own research, we also found that some of our course topics can be integrated with commercially available education material -- the TIMS Laboratory Investigations.[9] This material was developed at the University of Illinois at Chicago with the support of NSF. It adopted the integrative approach to teach/learn mathematics and science for grades 1 to 9. Of the 147 experiments listed in the program, twenty-nine of them were selected for use in both workshops because they fitted very nicely into our intended subject areas. The inclusion of the TIMS material into our workshop greatly enhanced the educational effectiveness of our curriculum.

The Curriculum

A) The First Summer Session. In the first summer session the following three subject areas were studied: (i) hands-on probability and statistics, (ii) application of concepts of force and motion -- science of sports, and (iii) simple machines.

Prior to the teaching of the three subjects listed above, we spent one session of instruction period to introduce two basic computer skills to participants. The first was on how to use a spreadsheet software program to process experimental data, and the second on how to use the Internet effectively for educational purposes. Participants' skills with computer usage were further enhanced as they used the software to analyze and plot experimental data gathered from their laboratory work, and to use the Internet to search for information relevant to the learning process.

In the hands-on probability and statistics session, the following five topics were covered: interrelation between probability and statistics, basic probability laws, concept of mathematical expectation, elementary statistics, and graphical presentation of experimental data. Three sets of discussion problems and nine hands-on experiments from TIMS were used to complement the study. The study of probability and statistics provided the basic tool for conducting hands-on experiments in other subject areas. On the other hand, the application of statistics and probability to analyze experimental results not only further reinforced the concepts of these two subjects, but also effectively demonstrated the integrative nature between mathematics and science.

The second subject area was the science of sports. The focus was on the study of concepts of velocity, acceleration, forces, and Newton's laws of motion. Activities such as running, jumping, throwing balls, and other subjects were used to illustrate the application of the concepts mentioned above. Eleven hands-on experiments from the TIMS program on measurement of velocity, acceleration, and the laws of motion were incorporated into the study.

The third subject area was related to the study of simple machines. The focus was on the concepts of equilibrium, free body diagram, and mechanical advantage. Three experiments from the TIMS program concerning the study of levers, incline planes, and wedges were used to complement the study. To culminate the study, participants also designed and constructed a catapult. A design competition was held at the conclusion of the workshop.

B) The Second Summer Session. The curriculum material of the second session was related to energy. The study was built on the foundation of knowledge covered in the previous summer session. Topics included the concepts of work and energy, and the application of these concepts to the study of renewable energy and energy balance in human bodies. These topics were chosen for two reasons. First, they are multidisciplinary involving an integrative knowledge of mathematics and various branches of science. Second, the scope of study was very broad and flexible to allow teachers to tailor the materials to meet their own needs.

Six experiments from the TIMS program were used to illustrate the concepts of work, kinetic and potential energy. These concepts were applied to illustrate selected topics in wind and solar power, as well as energy balance in human body.

Wind power topics included a discussion on the cause of wind and the historic use of the wind, and hands-on activities included a field trip to a wind farm, measurement of wind velocity and direction, and model windmill testing. In solar energy study, the discussion was focused on the availability of solar energy and solar collectors, while the hands-on activities included the measurement of power output from solar cells and the measurement of direct and diffused radiation. Topics for energy balance on the human body included the study of body metabolism and its relation to the combustion process, energy intake and expenditure. The study was accompanied by laboratory measurement on blood pressure, pulse rate, and breathing rate for various physical activities. These data were then used to calculate the metabolic rate for various types of physical activities.

We also used the Blackboard software as a forum for discussing problems and ideas about the learning in the workshop. It also served as a vehicle for disseminating education materials.

Closure

The workshop was a complete success. Teacher participants went back to their schools with many ideas and projects and education materials covered and developed in the workshops were used successfully in classroom teaching. The teaching units developed by the teacher (27 produced to date) have been posted on Blackboard so that teachers have access to all of the units. Many of the participants had shared their learning experience with their colleagues and played a leadership role in developing new approach and curriculum in their school districts. Working in a cooperative learning environment, participants gradually formed a community where they enjoyed great camaraderie and shared ideas and experiences even after the workshop was completed. All in all, the satisfaction level of participants was very high.

We believe the success of the workshop was due to the following factors:
1) Interesting subject matters -- All topics covered in the workshop were not only stimulating and challenging, but also closely matched with the national and state standards. In addition, they could easily be related to daily life experience and thus were familiar to learners.
2) Effective instructional methods -- Hands-on activities and group learning were combined to create an active learning environment. Such an environment was conducive to effective learning of mathematics and science subjects. In particular, the hands-on activities were built on the strengths of rural students since many of them are familiar with machines. After practicing this method in the workshop, participants were eager to adopt the method to their own teaching.
3) Need-orientated focus -- The curriculum was finalized after we gathered the input from participants. Most of the lecture material and all the laboratory experiments were directly transferable to classroom teaching.
4) Emphasis on computer usage and cooperative learning – The computer was used throughout the entire workshop to process and plot experimental data. Since the background and computer skills of participants were quite diverse, cooperative learning was found to be very effective in addressing the problem.
5) Innovative experimental devices -- A number of simple yet effective education devices (e.g., an inclined-plane system to measure acceleration, a pendulum) for conducting the hands-on activities in the workshop were designed and built at the machine shop of the University. These devices were later given to the participants to take back to their school. More importantly, showing how to build these devices also encouraged participants to develop new devices according to their needs.

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