
Integrating Technology, Science, and Mathematics Education

James E. LaPorte (Associate Professor,
Virginia Polytechnic Institute and State University)
Blacksburg, Virginia

Mark E. Sanders (Associate Professor,
Virginia Polytechnic Institute and State University)
Blacksburg, Virginia

Not since the launching of Sputnik had proponents of educational reform been so vocal about the status of science, mathematics, and technology education in America as they became in the 1980s. Throughout that time period, one national report after another lamented the problems confronting science and mathematics education in this country. While our brightest students were on par with the rest of the world, the majority of children in America were losing interest in science and mathematics and falling behind their worldwide peers with respect to science and mathematics achievement (see, for example, Exxon Education Foundation, 1984; International Association for the Evaluation of Educational Achievements, 1987 & 1988; National Assessment of Educational Progress, 1989; National Science Board Commission on Precollege Education in Mathematics, Science, and Technology, 1983; National Science Foundation and the U. S. Department of Education, 1980).

Sputnik had resulted in reform for science and mathematics education. This time, a battle cry rang out in the name of technology as well. The American public, the national reports on educational reform, and the different factions of the educational community spoke unilaterally on America's need for technological literacy in addition to the need for higher achievement in science and mathematics. Increasingly, science was being referred to in print as *science and technology*. Educational leadership in both

the science and mathematics communities began to promote aggressively the idea of integrating technology into their respective curricula. Concurrently, the field of industrial arts education was undergoing a long called for transition to technology education—a paradigm shift that included a new name as well as new directions in the curriculum.

Specific events occurring throughout the 1980s in each of the three school disciplines of science, mathematics, and technology education provided for the first time a milieu for collaboration. In effect, proponents of reform in all three of these disciplines called for connections to the other two. As the 1990s unfolded, the time was ripe for curriculum reform efforts directed at formally integrating the three disciplines.

THE SCIENCE EDUCATION COMMUNITY

The science education community first began to champion the importance of technology in the curriculum with the Science, Technology, and Society (STS) movement. During the past two decades, STS curricula have gained visibility on college campuses, and to a lesser extent, in public schools (Kranzberg, 1991). While the architects of the STS movement and curricula have primarily been scientists, and the curricula tend to reflect more natural and social science than technology, STS proponents have long promoted the importance of technology in this mix. Publications from and conferences with those in the STS community dating to the 1970s began to develop an awareness of technology in the science community. The STS advocates pointed to the fact that science education was serving too small a percentage of the American population, and that a clear focus on technology was necessary to interest the majority of students in science. Rustum Roy (1989), one of the most active STS education proponents, suggested that “there should be radically new curriculum options which would combine much more hands-on practical learning—not far from present Technology Education curricula, but with more science” (p. 9).

The most visible push for the integration of technology into science education, however, came in the late 1980s with Project 2061, which was supported by the American Association for the Advancement of Science. This massive project, designed to span several decades, was described as “a three-phase plan of purposeful and sustained action that will contribute to the critically needed reform of education in science, mathematics, and technology” (American Association for the Advancement of Science, 1989, p. 3). Connections between science and technology are one of the salient features of their published report, entitled *Science for All Americans*, written by the Project 2061 staff in consultation with the National Council on

Science and Technology Education. Significantly, none of the council members were from the technology education community, yet their interest in technological literacy is evident throughout the report.

Project 2061 followed *Science for All Americans* with six panel reports, one of which was simply entitled *Technology* (Johnson, 1989). More than any other single document, *Technology* defined the rationale and structure of technology education for those in the science education community. Ironically, industrial arts/technology education professionals had worked for four decades to define the field, yet it was Johnson's brief report that both defined and legitimized technology education for science educators. For the first time, the science education establishment began to recognize the critical role that technology education could and should play in the schools. "Technology education should reveal the process of technology as it evolves from ideas to fruition. This can best be learned using laboratory experiences to augment classroom instruction. Likewise, such education should show how technology affects individuals and society" (p. 3).

Johnson (1989) not only defined technology education for the science community, he clarified the inseparability of science, mathematics, and technology:

The sciences and mathematics are important to the understanding of the processes and meaning of technology. Their integration with technology education is vital. . . . Thus, a sound base in mathematics and biological, physical, and social sciences is vital to an understanding of modern technology. They should be part of technology education curricula, just as technology education should serve to bring additional meaning to the curricula of the sciences. (pp. 3-7)

In science education, another major initiative that recognized the role of technology in the curriculum, albeit to a lesser extent than did Project 2061, was the Scope, Sequence, and Coordination of Secondary School Science (SS&C) Project, directed by the National Science Teachers Association. *The Content Core: A Guide for Curriculum Designers* (National Science Teachers Association, 1992) provided a structure for science curriculum developers. The project developed a variety of different curriculum models along these guidelines and began to field test them around the country. One of the project's field test sites implemented an STS curriculum to test the viability of this approach. While the integration of technology into the curriculum was not as clear a goal for the SS&C Project as was the case for Project 2061, technology was at least present in the rhetoric of its reports.

All of this talk of reform in science education, coupled with seeming universal praise for the standards that mathematics educators had developed in the late 1980s (National Council of Teachers of Mathematics, 1989),

led science educators to begin to develop science standards in the early 1990s. With support from the National Research Council, a National Committee on Science Education Standards and Assessment was formed, and they developed a series of “Working Papers” in an attempt to evolve a new set of standards for science education (National Research Council, 1992a, 1992b, 1993a, 1993b). This committee wrestled with their task, finding it difficult to agree on a set of standards, yet technology was addressed in each of the documents. The language of these standards generally referred to connections between science and technology, though the committee stopped short of describing anything too specific in this regard. These reports clearly suggested the science curriculum should deal with connections, relationships, and interactions between science and technology, while teaching *about* technology and engineering should be left to technology education (National Research Council, 1992a).

With all of this interest in the connections between technology and science education, the National Science Foundation (NSF) began, in the early 1990s, to solicit proposals actively from the technology education profession. Proposals of this type funded by NSF included Phys-Ma-Tech (Scarborough, 1993a, 1993b), The Technology, Science, Math Integration Project (LaPorte & Sanders, 1993), Integrating Mathematics, Science, and Technology Project (Loepp, 1991), and Project Update (Todd, 1992). These projects were manifestations of the interest that science educators had in technology education.

THE MATHEMATICS EDUCATION COMMUNITY

Concerned about the need for reform in mathematics education, the Board of Directors of the National Council of Teachers of Mathematics established the Commission on Standards for School Mathematics in 1986. The commission produced *Curriculum and Evaluation Standards for School Mathematics* (National Council of Teachers of Mathematics, 1989), a document that had an immediate and resounding impact among mathematics educators as well as those in the broader arena of education. The curriculum portion of the *Standards*, as the document was commonly known, was “designed to establish a broad framework to guide reform in school mathematics in the next decade. In it a vision is given of what the mathematics curriculum should include in terms of content priority and emphasis” (p. v).

The curriculum *Standards* was divided into three sections: grades K–4, 5–8, and 9–12. It identified 13 curriculum standards for grades K–4, 13 curriculum standards for grades 5–8, and 14 curriculum standards for grades 9–12. The first four curriculum standards were the same for each of these three levels. They were Mathematics as Problem Solving, Mathematics as Communication, Mathematics as Reasoning, and Mathematics Connections. These and the other new mathematics curriculum standards were a very different way of defining mathematics curriculum. They communicated mathematics to educators in other disciplines in a much different light and served to open the door for collaboration with science and technology education. The language that appeared in the *Standards* ran parallel to the rhetoric of technology education. Phrases such as “problem solving,” “real world situations,” and “connections to technology” could be found throughout it. While technology in the *Standards* generally referred to graphing calculators and computers, the language nevertheless provided a rationale of sorts for the establishment of curricular ties between mathematics and technology education.

The *Standards*, for example, was emphatic regarding the need for problem solving: “Problem situations that establish the need for new ideas and motivate students should serve as the context for mathematics in grades 5–8” (p. 66). The first standard on problem solving was even more specific:

The curriculum must give students opportunities to solve problems that require them to work cooperatively, to use technology, to address relevant and interesting mathematical ideas, and to experience the power and usefulness of mathematics. . . . Real-world problems are not ready-made exercises with easily processed procedures and numbers. Situations that allow students to experience problems with ‘messy’ numbers or too much or not enough information or that have multiple solutions, each with different consequences, will better prepare them to solve problems they are likely to encounter in their daily lives. (p. 76)

The fourth standard, Mathematics Connections, even mentioned our field, among others, by name: “A topic such as measurement has implications for social studies, science, home economics, industrial technology, and physical education and is increasingly important teacher of these subjects” (p. 86). It is clear from the *Standards* that mathematics educators were not focusing on technology education, per se, as a sole collaborator in curriculum development, yet the language in the *Standards* was at the very least highly *encouraging* of such collaboration, perhaps for the first time. While the personal and professional connections between mathematics and tech-

nology educators were not yet in place when the National Council of Teachers of Mathematics' document was written, the authors nevertheless laid the foundation for those connections to begin.

In the early 1990s, tangible connections among mathematics and technology educators did begin to occur. One such example was Making the Connections: Mathematics/Science/Technology, sponsored by the Indiana State Department of Education in February, 1993. Billed as "The First Annual" conference on connections among the three disciplines, it attracted more than 1200 public school educators from around the state, the vast majority of whom were mathematics teachers. Significantly, more than a third of the presenters were from the technology education arena.

THE TECHNOLOGY EDUCATION COMMUNITY

With the name change from industrial arts to technology education, there came a renewed search for curriculum initiatives that would distance the new technology education from the image and curriculum of industrial arts. In the early 1980s, technology education proponents were championing the incorporation of social implications of technology into the curriculum as one of the key differences between the old and new paradigms. An increased emphasis on the so-called problem-solving method, making it more politically correct in the profession than the project method, was another one of the changes that occurred in the 1980s.

By the end of the decade, however, the field collectively seemed to lose some degree of interest in the social implications emphasis. It shifted its emphasis to the integration of technology education content and method with other school subjects. Many would-be technology teachers were concerned that in stressing the social implications of technology (as with STS), the field would surrender some or all of its commitment to the hands-on laboratory activities that had sustained the field for a century. The mix of technology, science, and mathematics was somehow more palatable to this contingency, perhaps because the curricular integration of these areas is more closely connected to the laboratory approach to instruction. That is, activities that integrate technology, science, and mathematics are essentially engineering activities, which, are inherently laboratory-based investigations with which technology teachers are quite comfortable. Thus, the idea of integrating these three areas seemed to catch fire among technology educators in the early 1990s.

While this was not really a new idea, (see, for example, Lux, 1984; Maley, 1973), it was a trend that gained increasing acceptance among technology educators as the 1990s unfolded. The discussions in industrial arts/technology education generated by curriculum development in the 1960s and 1970s, as well as the social implications discussions of the 1980s had, in effect, paved the way for the acceptance of the idea of integration with science and mathematics. Because of those earlier curriculum efforts, the field was ready for the approach to the study of technology that integration with science and mathematics offered. As evidence of the interest, more than 90 individuals participated in the first national workshop on the integration of technology, science, and mathematics at the annual conference of the International Technology Education Association (LaPorte & Sanders, 1992). A year later, the International Technology Education Association (ITEA) conference program included many presentations on the integration of technology with science and mathematics.

In the 1990s, technology education supervisors at the state and local levels began to fund projects that integrated these three areas. Increasing numbers of articles on this topic were published in the professional literature, and commercial curriculum materials surfaced, for the first time, at the 1993 ITEA conference. Most importantly, public school technology teachers began to be recognized for their innovative efforts along these lines. Greg Sullivan, Virginia's 1992-93 Teacher of the Year, for example, was a middle school technology teacher who had integrated science and mathematics into his technology education curriculum.

Parallel to these events was a \$2 million initiative from the United States Department of Education. The Technology Education Act of 1990 resulted in funding for a series of technology education demonstration projects that integrated technology education with science and mathematics (Wicklein et al., 1991). These regionally distributed projects provided visible evidence of the integration of the three school subjects.

RESEARCH WITH IMPLICATIONS FOR THE INTEGRATION OF TECHNOLOGY, SCIENCE, AND MATHEMATICS

Hands-On Science versus Hands-On Technology

Hands-on is one of the hallmarks of technology education but the science community, like virtually every discipline taught in the school, also uses the term. Haury and Rillero (1992) stated that instructional approaches that

“involve activity and direct experience have become collectively known as hands-on science” (p. 2). There are differences between hands-on science and hands-on technology that stem from basic differences in the nature of the two disciplines: Science is a study of the natural world whereas technology is a study of the human-made world. In both science and technology, there is an emphasis on problem solving. In science education, the problems in which the students are engaged are typically related to scientific laws and principles, knowledge that is already known by the science community. There is, therefore, a single, best solution to a particular problem (though there may be a wide variation in the methods used to arrive at the solution). Through working with problems, students can discover scientific laws and principles. They observe phenomena, formulate hypotheses, test their hypotheses through experimentation, and draw conclusions. Through this discovery, the learning is more engaging and interesting to the student and is therefore likely to be more permanent.

On the other hand, in technology education, as a study of the human-made world, students are engaged in solving practical problems. They design, construct, and evaluate their solutions. Just as there is no single best automobile, can opener, or building design, there is no single best solution to any of the problems that the students encounter.

In scientific investigations, it is essential that the particular variable under study be isolated from all the other variables that might have an influence on the outcome. For example, in conducting experiments on Newton’s laws of motion, an air track might be used. The air track has a series of holes in it through which compressed air passes. This creates a nearly frictionless surface over which the vehicle being used to show Newton’s laws can pass. The result is that friction has been rendered negligible. This isolation of variables is often the major challenge of scientific research.

The challenge in technological problem solving, on the other hand, is to recognize that a multitude of variables exists and that there is a complex interaction among them. Friction, for example, almost always has a negative effect on experiments in physical science, but friction in the world of technology can have both negative and positive effects. For example, a vehicle with minimal friction between the tires and the road surface requires less power to move it. An optimal level of friction is required, however, so that the vehicle can be adequately (and safely) guided along the road surface.

Another difference between hands-on science and hands-on technology is the amount of time spent doing it. Though no recent quantitative studies were found that addressed this question, it is safe to say that hands-on activity occupies the vast majority of the students’ class time in technology education, but even in activity-based science classes, hands-on activity

represents a relatively small proportion of class time. Bredderman (1982), for example, found that only 19% of the students' time was devoted to hands-on activity in what were termed "activity based [science] programs" (p. 41). Nonetheless, this was roughly twice the time devoted to activity in traditional science programs.

Science Research Relating to Hands-On Activities

Early research on the effectiveness of hands-on activities in science produced mixed results. For example, Kruglak (1953), in a study of college level general physics students, found that there was no significant difference between students who had a lab and those who did not in their performance on written physics achievement tests. Those who had the lab, however, achieved higher when it came to tests dealing with lab work.

During the 1960s, a considerable amount of federal money was invested in developing improved science curricula. The Biological Science Curriculum Study, the Earth Science Curriculum Project, and the Physical Science Curriculum Committee (1960) are examples of some of the noteworthy efforts. All of these utilized an inquiry approach and hands-on activities extensively, but by the end of the 1970s, most of these projects had disappeared. In reference to the situation at the elementary school level, Mechling and Oliver (1983) stated the following:

The science classroom goes on—impervious to the findings of research. Except for a brief flirtation with inquiry or hands-on methodology in the 1960s, elementary science is taught pretty much as it always has been. Maybe the textbook is now in four colors, but the old read-recite-discuss way is as entrenched as ever. (p. 41)

This motivated Shymansky, Kyle, and Alport (1982) to conduct a meta-analysis of 34 studies that had been done on these new curricula. They concluded that students in these earlier hands-on programs had performed better, on a multitude of criteria, than had students in traditional, textbook-based programs. They also found that students' attitudes were more positive about the newer programs than about traditional programs. Apparently, the programs vanished due to other factors such as cost and the preparation time required on the part of the teacher. Instructional time was found to be an impediment in studies by Tilgner (1990) and Morey (1990).

Since the Shymansky et al. (1982) study, other meta-analyses have been conducted on the effectiveness of hands-on approaches to the teaching of science. Bredderman (1985) synthesized 57 studies of the use of hands-on activities and inquiry-based teaching, encompassing 13,000 students in over 1,000 classes. He concluded the following:

It appears that the programs' design to encourage the use of laboratory science, starting in the elementary school years, does in fact result in improved student performance in a number of valued curricular areas. Based on the available research evidence, it also appears that the use of inquiry based programs increases the amount of student laboratory activity and decreases the amount of teacher talk in the classrooms. (p. 586)

Two of the valued areas that Bredderman's meta-analysis addressed were achievement and motivation.

Cotton and Savard (1992) reviewed 44 studies that were conducted on intermediate level science and mathematics instruction. They concluded that activities such as "student projects and presentations," and "field trips and laboratory experiments" have a positive effect on achievement and affective outcomes (p. 9). In addition they concluded that activity-based instruction is particularly effective with remedial students. They cautioned that activity-based instruction may be best used in combination with some of the traditional methods such as lecture, discussion, and demonstrations.

Hands-on activities have also been shown to have a positive effect on the ability of students to solve problems. Glasson (1989) conducted an experiment with ninth grade physical science students on a three-week unit on simple machines. He compared students taught by demonstrating science experiments to students actually doing the experiments. He found that the physical manipulation of laboratory equipment was not a factor in improving declarative knowledge (factual and conceptual), consistent with four other research studies he cited. Students in the hands-on group, however, performed significantly better on the procedural knowledge (problem-solving) test used in the study. He concluded that all students, regardless of reasoning ability, benefited from hands-on laboratory instruction. He also concluded that hands-on activities "promote peer interaction where students are free to argue, make mistakes, and challenge each other" (p. 129).

Overall, one can conclude that hands-on science is, indeed, more effective than traditional approaches in at least two principal ways. First, it increases student achievement, especially if the evaluation instruments measure more than the mere memorization of facts (see Brooks, 1988; Mattheis & Nakayama, 1988; Saunders & Shepardson, 1984). This is perhaps why Kruglak (1953), a study mentioned earlier, found that the laboratory component of a physics course made no difference in student achievement on written tests. Second, hands-on science tends to improve the attitude of students toward science (see Jaus, 1977; Kyle, Bonnstetter, Gadsden, & Shymansky, 1988; Kyle, Bonnstetter, McCloskey, & Fults, 1985;

Rowland, 1990). One could argue that a student's attitude toward science is an essential prerequisite to learning the subject matter.

Even though there is mounting research evidence about the value of hands-on activities, the science community has a long way to go before this method becomes a significant part of instruction. In a large-scale study reported by Weiss (1987), lecture/discussion was found to be the typical teaching method used in science classes. Hands-on activities were more predominant in elementary school than in the secondary level (51% of the lessons versus 43% in middle/junior high and 39% in high school). The vast majority of teachers believe that hands-on activities are more effective than traditional methods. Yet, ironically, Weiss found that hands-on activities were used to a lesser extent by teachers polled in this study than they were in a comparable study reported in 1977.

Mathematics Research Relating to Hands-on Activities

A significant amount of research has been conducted in an attempt to determine the effectiveness of hands-on activities in mathematics. Manipulative activities, as they are referred to by math educators, became popular in the 1980s, and there is ample research to suggest that manipulative activities are, in fact, an effective way of teaching mathematics concepts. Variables such as achievement, long term retention, teacher and student attitudes, assessment strategies, and differential impacts upon varying ability students are among those that have been studied with respect to manipulative math activities. Although manipulatives have been used more at the elementary grades than in later years, the research spans the kindergarten through college continuum.

Lenoir (1989) analyzed 45 studies of the effects of manipulatives in mathematics instruction from kindergarten through college. He concluded that students in grades 6–9 who used manipulatives in learning measurement skills demonstrated greater achievement than those who did not use manipulatives. Moreover, those students retained more after one to four months with respect to measurement and other mathematics concepts than those who did not participate in manipulative activities. Manipulatives have been particularly effective and extensively used by teachers in the elementary levels. This is consistent with Piaget's work, which suggests that children under the age of 11 are not able to think in abstractions. Concrete examples are, therefore, particularly helpful to them.

A variety of findings supportive of hands-on activities in mathematics have been discovered by a number of different researchers. Among those findings are the following:

1. Simon (1991) conducted a descriptive study of 80 third and fourth grade students who received manipulative based mathematics instruction and found students to be more “focused” during manipulative lessons. Both the teachers and students in Simon’s study believed that manipulatives enhanced the understanding of mathematics. Simon also concluded that it is practical to incorporate manipulative activities into the mathematics curriculum over the course of a full year.
2. Sigda (1983) developed and evaluated manipulatives for teaching multiplication to third grade students. The treatment presented content via a *sequential-modal* approach which included manipulatives, pictorial information, and symbolic representations. Sigda found that the use of the sequential-modal approach resulted in significantly greater acquisition and retention of the basic multiplication combinations, array translation skills, and skills in operation identification among the third grade students.
3. Canny (1984) studied the relationship of manipulative instructional materials to achievement in fourth grade pupils. Students who used manipulatives for the introduction and reinforcement of concepts scored significantly higher on two achievement tests than did the control group using the textbook activities.
4. McCoy (1989) looked specifically at the perceptual preferences of mathematically deficient elementary school students. Comparing students in need of remediation with average or above average math students, McCoy found the former group to prefer a kinesthetic mode of instruction and concluded, “the results of this study strongly support the use of concrete manipulatives and related activities” (p. 9).
5. Prigge (1978) and Kipfinger (1990) each studied the use of manipulatives to teach geometry concepts to sixth grade students. Prigge used solid objects to aid with instruction and found positive significant effects for low ability students, but no effects with high ability students. In a similar study, Kipfinger found statistically significant results in favor of the manipulative method of instruction for geometry.

While manipulatives have been common in elementary school mathematics, their paucity in middle schools led to a study by Tooke, Hyatt, Leigh, Snyder, and Borda (1992). They interviewed 30 teachers from grades 4 through 8 to assess their attitudes regarding the use of manipulatives and to find out why few middle school teachers made use of manipulatives. Two general findings emerged. First, middle school teachers had generally not

received training with manipulatives and were, therefore, uncertain as to how to make use of them in instruction. Second, teachers felt manipulatives were simplistic and thus inappropriate for students above the fourth grade level. Teachers said things such as "manipulatives were too far beneath them," and students in fifth grade "needed" abstract teaching. The researchers noted, however, that certain manipulatives such as Geoboards and Mira were designed for middle school students.

Certain logistic problems that surfaced in their study were reminiscent of those confronting teachers today who wish to integrate mathematics with technology education. After the fourth grade, for example, teachers felt the pressure to complete the math curriculum left too little time for manipulatives. Another compounding variable mentioned was the lack of support for the purchase of manipulatives for middle school students.

Despite these impediments, manipulatives have been used at times in middle and high school mathematics instruction. Meira (1992) presented eighth grade students with physical devices: a winch, a device with springs, and a computerized input-output machine. The intent of the study was to determine the role that designing (which was viewed as a manipulative) played in mathematical sense making. Meira found that graphic representations on paper provided the material basis for mathematical activity. These representations were not simply recalled, but rather were reconstructed with regard for the physical setting of the activity. They were, therefore, important to the student's ability to make mathematical sense of the problem at hand.

Balka (1983) experimented with mathematics manipulatives to teach computational skills to mildly handicapped students in a high school pre-vocational program. He found computational achievement increased on all subtests and composites except on the simplest arithmetic test. These findings led Balka to conclude that the use of manipulatives improved the computational skills of slow learners. He also found that manipulatives were motivating for students and resulted in increased class discussion.

Technology Education Research Relating to Hands-On Activities

As with the programs that preceded it, hands-on learning is the hallmark of technology education. It exemplifies the thinking of noted experiential philosophers and theorists such as Pestalozzi, Rousseau, and Dewey. Unfortunately, very little research has been done to show the relationship of hands-on activities to cognitive learning in technology education. The history of the profession offers some explanation for this void. Though there was much literature generated to support the theory that activities should

serve as the means to an end and that learning should include the cognitive domain, actual practice in earlier programs was principally focused upon developing skill in the use of tools and machines (Dugger et al., 1980). In other words, the hands-on activities were not the means to cognitive knowledge, they were often the end itself. Even in contemporary programs, if one believes that technology is thoughtful doing (Towers, Lux, & Ray, 1966), then a focus upon activity, or doing technology, is understandable and defensible.

The lack of research in the connection between activities and cognitive knowledge compelled Korwin and Jones (1990) to conduct a study to determine if cognitive knowledge increases when technology-based, hands-on activities are used to supplement regular classroom presentations. Their subjects were eighth graders and the instructional unit was geodesic domes. They found that the hands-on activity of actually building a geodesic dome improved performance on a cognitive achievement test about the instructional unit. They did not find any difference, however, between the two groups in retention of knowledge after two weeks. Korwin and Jones made an important point about the lack of research in this area. It is quite likely, however, that the findings reported earlier on the value of hands-on activity in increasing cognitive understanding in mathematics and science would be applicable to technology education. Nonetheless, more research is certainly needed in this area.

With the exception of the Korwin and Jones study, most research on activities has been at the elementary level and has dealt with the efficacy of technology activities in promoting understanding in other subjects. Early research efforts by Champion (1966), Downs (1969), Logan (1973) and Pershern (1967) showed that industrial arts activities incorporated into science and/or mathematics instruction enhanced achievement, motivation, or both. More recently, Kowal (1985) compared elementary school mathematics and science students who were taught using constructional (industrial arts) activities versus those who were taught without such activities. He found that students were more motivated in mathematics classes that incorporated the activities than they were in social studies classes. Also, motivation was higher in mathematics classes taught using the activities than in traditionally taught classes.

Brusic (1991) examined fifth grade students' achievement and curiosity relative to a science unit in which technology activities were integrated. She also investigated whether students' curiosity about the unit prior to studying it was related to their achievement. She found that the group that was engaged with the technological activity had a significantly higher level of curiosity than the control group. She found no significant differences in science achievement. Brusic concluded that the integration of technological

activities with science instruction may positively affect students' curiosity, but may not enhance or deter from their science achievement. Hence, the science-technology linkage shows promise as a useful method of promoting greater student curiosity without negatively affecting their achievement.

Though not done by researchers within the field of technology education, three studies exemplify direct implications of the value of the hands-on approach and content of technology education relative to science and mathematics. Cohen (1992) cited research showing that the majority of late adolescents and adults in the United States function at Piaget's concrete operational level rather than at a formal (abstract) operational level, refuting the Piagetian notion that the transition to formal thought occurs at about age 11. He also cited evidence that science is taught, for the most part, abstractly. From his study, he concluded that most middle school level students and a significant portion of high school students are not able to understand science concepts. It is, therefore, imperative that science be taught in a concrete manner for most students. The applied nature of most technology problems certainly offers potential in providing the concrete learning experiences about which Cohen wrote.

A second study with implications for technology education was done by Hoffman (1989), a German science educator. Her work was motivated by a belief that interest is the most important requisite to learning and that disinterest in science is an international phenomenon. Science programs must, therefore, be restructured so that they increase interest. In her study, she investigated students' interest in specific kinds of activity that relate to science and then asked them to compare the amount of time spent doing that kind of activity in science classes. She found that "Testing something, taking a device apart or putting it together" was ranked 2nd among females and 1st among males across nearly all grade levels in terms of interest. Among females, this was ranked 10th of the 12 forms of activity actually done in the science class. Among males, it ranked 11th. "Inventing something, designing a device" was ranked 6th among females and 4th among males at the 10th grade level in terms of interest, yet it was ranked last in terms of the students' perception of how often they were allowed to engage in such activity in science class. Hoffman also found that the context in which science is studied is important. For example, males tended to be equally interested in learning about pumps in either the context of an artificial heart or in transporting petroleum products. Females preferred, however, the artificial heart. Hoffman's study shows that students have a keen interest in what happens in technology education, yet they actually have little opportunity to do it, at least in science class. Her work also suggests that there are gender differences regarding the technological contexts.

Finally, White (1979), an Australian science educator, synthesized litera-

ture on memory recall. He contended that long term memory related to the understanding and recall of science concepts can be enhanced through the development of personally involving episodes. He argued that the typical science lab does not produce such episodes and lacks any relationship to the real world. As a solution, he suggested the following:

Kinematics experiments . . . might be better done with people, bicycles, and cars than solely with trolleys and airtracks; experiments on refraction might involve swimming pools rather than glass blocks; and electricity might be better studied with house fuses, switches and meters or with torches in their commercial cases than with rheostats and potentiometers. As well as providing more recallable and useful generalised episodes these changes could make students see physics as a more relevant study in their lives than they do now. (p. 386)

White (1979) suggested that three types of experiments should be considered in physics. The first type is “the unusual experiment which engages the emotions through being odd, dramatic, beautiful or puzzling” (p. 387). A second type links “school subject matter and daily life . . . providing experiences which will be called into play in making subsequent information comprehensible” (p. 387). A third type involves “true problem solving” (p. 387). The integration of technology, science, and mathematics seems quite clear in White’s conclusions.

Though fewer in number than the studies conducted by the science and mathematics community on the use of hands-on activities, the results of research on the use of technology activities to augment science and mathematics instruction are remarkably similar. Like hands-on science and mathematics, hands-on technology integrated into science and mathematics classes tends to improve motivation (or curiosity) and achievement, but a key question remains unanswered. Does hands-on activity, simply by itself, account for the improvement? Nearly all the studies conducted by the science and mathematics community compared hands on to traditionally taught classes. There was little evidence that one hands-on method was superior to another. Most of the studies done by technology educators were conducted years ago and even the most recent studies did not truly engage students in technological problem solving as it is thought of today. For the most part, they were simply constructional activities. Whether or not technology problem-solving activities uniquely contribute to the motivation and achievement in science and mathematics is unknown. Yet, there is at least some research evidence from outside the field that suggests that the concrete, real world nature of the programs may be particularly suited to the

needs and interests of students to augment their understanding of science and mathematics.

CURRENT NOTIONS OF INTERDISCIPLINARY INSTRUCTION

The notion of the teacher as the fountain of knowledge pouring wisdom into the minds of youngsters runs contrary to constructivism and the recent work of cognitive psychologists. Learning is increasingly viewed as mediated by context. One of the criticisms leveled by the *High School* report was the unnatural separation of content that had occurred in the public schools. As Boyer (1983) wrote on the committee's behalf: "While we recognize the integrity of the disciplines, we also believe their current state of splendid isolation gives students a narrow and even skewed vision of both knowledge and the realities of the world" (pp. 114–115).

Schools have made considerable headway on the task of amending this situation since the early 1980s when Boyer made his observations. The middle school movement, which began more than two decades ago and has gained a great deal of momentum in recent years, is predicated on interdisciplinary teams and a core curriculum (Vars, 1987). Regrettably, technology education is almost universally omitted from the teams, which are generally comprised of the "academic" subject areas: language arts, social studies, science, and mathematics.

At the elementary level, programs such as "Whole Language," "Writing Across the Curriculum" and "Math Their Way" have been very successful at breaking down artificial barriers among the traditional content areas. High schools, under the tight reins of standardized tests and college entrance requirements, have been particularly slow to cross over the traditional curriculum boundaries, but they too are exploring options along these lines. Thematic instruction, in which teachers from different disciplines relate lessons to a pre-determined theme, has served as a popular means of integrating content at all levels of education.

In light of contemporary research on cognitive theory, educators in general and the science and mathematics educators in particular have come to realize the limitations of teaching in relative isolation. Many now feel that science and mathematics taught as abstractions divorced from reality are of relatively little use. As Langbort & Thompson (1985) articulated, "An important instructional principle, strongly validated by recent educational research, is that children learn science and mathematics more effectively

when they can concretely connect experiences with principles they are studying in various subjects” (p. 8).

SOME RECENT MODELS OF CURRICULUM INTEGRATION

A substantial number of models for integrating technology, science, and mathematics have been developed and implemented. In addition to the relatively recent work being done to integrate all three of these areas, the Science, Technology, and Society (STS) movement and the Teaching Integrated Math and Science Project (TIMS) are notable examples of integration. The STS movement got under way more than two decades ago as science educators began to recognize the interconnected nature of science and technology. As Gallagher (1971) stated, “To make an unnatural separation of the two, teaching only a so-called basic science, excluding technology, leaves learners with an unrealistic picture of the workings and results of the scientific enterprise” (p. 333). In the early 1980s, STS advocates were successful in convincing the National Science Teachers Association to develop a policy statement promoting the implementation of STS (Bybee, 1991). Research has brought to light a number of positive outcomes of STS programs (see, for example, Yager, 1988a; Yager, 1988b; Yager, Blunck, Binadji, McComas, & Penick, 1988).

The Teaching Integrated Math and Science Project (TIMS) at the University of Illinois at Chicago has been developing curriculum materials that connect mathematics and science since the late 1980s. In 1991, the National Science Foundation (NSF) awarded the project an additional \$4.2 million to develop a comprehensive integrated math/science curriculum for grades K–6. To date, the project has published more than 70 different activities that utilize this approach.

The Research and Experimentation course, outlined in the *Maryland Plan* (Maley, 1973), was one of the earliest efforts to integrate what was then industrial arts content with science and, to a lesser extent, mathematics. This ninth grade class was essentially a science experiment conducted by students in an industrial arts facility. Few industrial arts educators were ready to adopt this approach, though many of Maley’s ideas resurfaced two decades later after the formal transition to technology education. Maley’s work later led to *Math/Science/Technology Projects for the Technology Teacher* (Maley, 1984). In an effort to pull together content from all three disciplines, Maley had his students construct models of technological artifacts (e.g., a water-

wheel, block and tackle, hydraulic elevator, etc.) and then identify the scientific and mathematical principles connected to the artifact. Maley was among the first to recognize the importance of formally integrating science and mathematics into the technology curriculum. He noted the following in the “Introduction” to the monograph:

The current emphasis on mathematics and science provides a rich opportunity for industrial arts/technology education to establish itself as an important partner in contemporary education. . . . The impossibility for teaching any technological development to any extent within a single discipline makes a persuasive case for a partnership relationship as well as a requirement for integration of subject matter. Industrial arts/technology education has, within its content and methodology, a prime vehicle through which the subjects of the school are brought together for the purpose of meaning, understanding, and relevance on the part of the learner. (p. 7)

In the Fall of 1984, the “Resources in Technology” section of *The Technology Teacher* began to include a “Math/Science/Technology Interface” subheading. The idea was beginning to catch on in the field. In the waning years of the decade, a handful of innovative technology teachers began to incorporate science and mathematics into their curricula and/or work with science and mathematics teachers in their schools. The idea of integrating technology, science, and mathematics really seemed to take hold as the '90s came in, and a flurry of activity in this regard began to occur. Activities and curriculum development began in earnest at both the elementary and secondary levels.

FUNDED PROJECTS

United States Department of Education

In 1991–92, the United States Department of Education sponsored four regional demonstration projects that were intended to develop models for the integration of technology, science, and mathematics (Wicklein et al., 1991). These projects were among the first to fund project directors from the field of technology education. They enabled the directors to begin to develop materials that would integrate technology, science, and mathematics at both the middle and high school levels. Four different regions were represented: mid-America, Northeast, far-Northwest, and the Appalachian regions. The latter project resulted in curriculum materials that became commercially available upon completion of the project.

Elementary School. Content at the elementary level tends to be more integrated than at the secondary level. The Mission 21 Project sought to capitalize on this with a project that integrated technology-based problem solving for the elementary grades. In 1985, The National Aeronautics and Space Administration funded researchers at Virginia Polytechnic and State University to develop these curriculum materials for grades 5–6. Additional phases were subsequently funded: grades 3–4 in 1988, grades 1–2 in 1989, and preschool–K in 1992. The materials used thematic technology problem-solving activities to integrate mathematics, science, social studies, and language arts. The Level III (grades 5–6) materials, for example, were organized around four themes: Communication, Energy and Matter, Invention, and Space Colonization. All materials were field tested extensively throughout Virginia and the materials, including books carrying each of the theme titles and a teacher’s resource book, were commercially published in 1992 (Brusic & Barnes, 1992).

In 1992, the National Science Foundation funded another major project directed primarily at the elementary grades, but extending into the middle grades as well. The four primary objectives of Project Update were the following:

1. Develop curricular materials for grades K–8 that integrate technology, science, and mathematics reflecting a design and technology/engineering education approach;
2. Establish a clearinghouse to collect and disseminate integrated TSM materials;
3. Initiate collaborations with scientists, engineers, and technologists in the local community; and
4. Disseminate the work of the project through *Ties Magazine*. (Todd, 1992).

Middle School. The National Science Foundation provided substantial funding for two middle school projects focused on technology integration. The Technology, Science, Mathematics Integration Project, funded from 1991–1993, developed 15 activities designed to require the application of science and mathematics to solve technological problems (LaPorte & Sanders, 1993). It was believed to be the first attempt to develop comprehensive curriculum materials designed to encourage teachers in all three areas to work together. Though the middle school movement began to make great strides in terms of getting teacher teams working together, the technology teacher was systematically divorced from those teams. The

Technology, Science, Mathematics Integration Project materials required the technology teacher to be on the team with the science and math teachers, thereby facilitating a coordinated effort among all three teachers. Upon completion of the project, the activities were commercially available for use in middle schools.

The approach followed by the Technology, Science, Mathematics Integration Project was to develop technological problem-solving activities that would take perhaps one to three weeks to implement. This approach allowed teachers in each of the three areas to incorporate the activities into their existing curricula rather than to restructure their entire curricula. It was believed this would make it easier for the majority of teachers to attempt a technology, science, mathematics integration approach in their classrooms (LaPorte & Sanders, 1993).

There was also a perceived need for an entire curriculum that would integrate technology, science, and mathematics in the middle school. In 1992, the National Science Foundation funded the Integrated Mathematics, Science, and Technology Project (IMaST). The focus of this project was developing and field testing materials centered around the topics of biotechnology, manufacturing, and forecasting for seventh grade students. The project hoped to find solutions to some of the problems that impeded systemic change with regard to the implementation of integrated curricula.

High School. Several high school models emerged in the early 1990s as well. Technology teachers in Conroe, Texas undertook a thematic Space Simulation project at The Woodlands High School. The project, which received funding from the National Air and Space Museum, capitalized on America's fascination with space. It rallied the entire school around a space simulation, which they constructed in the technology education facility. Teachers throughout the school coordinated instruction with the project. Science experiments, for example, were designed by students and conducted during the several days that students spent physically isolated inside the "space station." The project resulted in, among other things, publication of *Space Simulation* (Bernhardt & McHaney, 1992), which challenged other schools to "design, build, operate, and evaluate a habitat for human beings in a hostile environment for a period of not less than 24 hours" (p. xi). The teachers involved even formed an international association to facilitate implementation of this type of activity in other schools around the world.

Phys-Ma-Tech (Scarborough, 1993a, 1993b) was another example of a high school project, funded by the National Science Foundation, that sought

to develop models depicting physics, mathematics, and technology teachers working together at the high school level. Phys-Ma-Tech utilized 15 teachers in five schools to develop and test various integration models. Among the benefits noted by Scarborough (1993b) were increased enrollments in physics and technology, higher test scores, and new teacher interest and support for the concept.

IMPLICATIONS FOR TEACHER EDUCATION

Technology Teacher Education

One can argue about which came first, technology or science, as well as what dependencies there have been between the two disciplines in the past (see, for example, DeVore, 1987). These arguments are important in establishing the foundation, lineage, epistemology, and scope of technology, but the interdependencies of technology, science, and mathematics in today's world are irrefutable. From a technology perspective, it seems moot to argue that a strong, conceptual background in science would not enhance one's ability to solve technological problems and to better understand the human-made world.

Logically, as the field moved away from trade-based courses and an emphasis on skill in the use of tools, it seemed that more attention would be given to assuring that prospective teachers had a strong background in science and mathematics. Apparently, this is not the case. Finch, Schmidt, Oliver, Yu, and Wills (1992) analyzed the transcripts of recent teacher education graduates in agriculture, business, home economics, marketing, technology, and trade and industrial education. In science credits, technology graduates completed an average of 9.3 semester hours, ranking only fourth among the six teaching specialties in the study. Only business (8.8) and marketing (7.6) required fewer hours. Fewer than one fourth of the technology graduates earned 12 or more semester hours in science. Most of the science semester hours that the technology graduates completed were in biology (3.9). Physics and astronomy courses were next, with an average of 3.1 semester hours. An average of 1.2 semester hours were completed in chemistry.

Technology education majors ranked fourth, as well, in the amount of mathematics and computer science course work completed, averaging 7.6 semester hours. Home economics and trade and industrial education were the only groups that averaged fewer semester hours (6.7 and 7.5 respectively). Only 9.3% of the technology graduates earned 12 or more hours

in mathematics and computer science, the lowest among the programs studied.

These are startling statistics. First, with the possible exception of agricultural education and its intimate dependence upon the biological sciences, it seems logical that technology education graduates would have completed more science credits compared to graduates of the other programs in the Finch et al. study. At least one would assume that the semester hours would be greater than those completed by trade and industrial education students. This was not the case. The credit hours completed by technology graduates in mathematics and computer science are somewhat less surprising, relative to the other teacher education graduates. For example, business students need a solid background in mathematics because of the importance of quantitative methods in their field.

Second, the sheer number of science and mathematics semester hours completed are disconcerting. Virtually all colleges and universities have had requirements for course work in the basic disciplines (mathematics, natural science, social science, and humanities) from their inception. In the recent decade, the perceived value of such course work has increased, resulting in corresponding increases in the semester hours required, through what are often called *core requirements* (see Lynch, 1990). As Finch et al. (1992) suggested, it is quite likely that the courses in science and mathematics completed by technology education graduates were simply the minimum number required by the institution for graduation.

On the other hand, it is somewhat encouraging that an average of 3.1 hours in physics and astronomy were completed, considering the close relationship between the content of existing technology education curricula and physics principles. This relative predominance of physics was greater by far than the average number of hours completed by graduates of the other programs in the study. The fact that most of the credits in science earned by technology education graduates were in biology might also be construed in a positive light. This is potentially an essential first step for teachers to deliver instructional programs in biotechnology, as some in our field are promoting (see, for example, Savage, 1991). Yet it could also be that the predominance of biology course work is due to the perception that biology is the "lesser of the evils" and easier. Moreover, one course in basic biology may not have any real value in implementing a biotechnology program.

There are a myriad of reasons for the rather limited background in science and mathematics among technology teacher education graduates. As technological knowledge increases and the field becomes broader, there is a tendency for course requirements in the program to increase. Courses required outside of the program may be seen as an impediment to assuring that the student has a sound grounding in the fundamentals of the field.

Many technology education majors are transfers from other programs including those of the engineering and engineering-related curricula. This phenomenon seems to be particularly prevalent in land grant universities where engineering is frequently the predominant curriculum. A major reason for the transfer decision is the lack of success the students have experienced in calculus and calculus-based physics, and foundation courses that serve to “weed out” students in engineering. Consequently, they arrive with a certain disdain for science and mathematics in general when they enter the technology education program.

Other students are attracted by the emphasis on practical, hands-on doing that typifies most technology teacher education programs. Perhaps through interest and success in technology programs in their earlier schooling, they seek more of the same at the college level. Perhaps they have already been turned off to science and mathematics through their earlier educational experiences. Consequently, they seek a curriculum at the college level from the perspective of what the curriculum does *not* require (a lot of science and mathematics) more than what it does include.

Technology teacher education programs have been waging a battle for a decade or more to keep enrollments at a level whereby they can continue to exist and supply teachers for the public schools. Many have lost that battle, especially in recent years. To some extent, the dearth of science and mathematics required of technology majors may be motivated by self-preservation. If the science and mathematics requirements are similar to the requirements of engineering, unsuccessful engineering students will not be attracted, nor will students who experienced failure in science and mathematics at the secondary level. Likewise, those who find practice more appealing than theory will not be motivated to enroll in a program that places theory in a prominent position. If the technology student and the technology teachers in the public schools have developed a disinterest or even a disdain for science and mathematics, the challenge of implementing programs that integrate the three disciplines is great indeed.

Even if discipline integration does not occur, it is still essential that the technology teacher exit the teacher education program with a solid background in science and mathematics if the ideals of technology education are to be realized. In the days of earlier programs in which students built projects following plans prepared by the teacher, knowledge of science and mathematics were only minimally applied. In the present era, where technological problem solving is the very core of the program, such knowledge is essential. Without it, a situation in which students try to solve technological problems using only the knowledge with which they entered the class will prevail. When these problems are solved, the teachers, like the

students they teach, will continue to have no idea of why solutions did or did not work.

Optimal solutions to problems such as building bridges, solar collectors, model submarines, and hydraulic robots, as well as the venerable CO₂ car, all rely heavily upon science and mathematics. Though students can solve these problems in the absence of science and mathematics without them, the potential for learning is dramatically decreased. This circumstance has led some technology education teachers to incorporate more science and math instruction into their technology classes. This approach to content integration requires technology teachers to be not only well grounded in science and mathematics, but also to possess the skills necessary to put the knowledge into teachable terms so students may effectively apply it. Most importantly, teachers must also be motivated and excited about the potential benefits of this approach for it to work.

The potential for both technological and scientific misconceptions abounds. Clearly, there are many voids to fill and chasms to cross if content integration is to be realized. To do so necessitates more than just requiring more credits in science and mathematics among prospective technology teachers.

Science and Mathematics Teacher Education

The dependence of technology on science and mathematics in solving technological problems was delineated in the previous section. Likewise, it seems foolish to think that one's ability to hypothesize about and understand natural phenomena would not be enhanced through an understanding of technology and real-world applications. In fact, the idea of practical application runs consistently through the new mathematics (National Council of Teachers of Mathematics, 1989) as well as through the science standards that are currently under development. A problem exists, however, because although the technology teacher may have had minimal course work in science and mathematics, the course work among science and mathematics teachers in technology is virtually nonexistent. While technology teachers typically have studied science and mathematics courses every year from 1st through 12th grades, it is highly unlikely that science or mathematics teachers have *ever* had a technology course.

According to Johnson (1993), there is only one institution in the country that requires all prospective teachers to complete course work in technology. Practical problem solving for science and mathematics teachers is often limited to the illustrations of technology in the textbook and "story problems" at the end of each chapter. Only those science and math teachers who have had real-world experience through previous employment or are

exceptionally creative will bring the technological world outside the school into their teaching.

Providing a technology knowledge base among science and mathematics teachers is difficult because of impediments that are parallel, but often opposite, to those that one faces in providing a science and mathematics base for technology teachers. Both science and mathematics teachers are ingrained in a culture that seeks to predict and explain phenomena. In science classes, every effort is made to control the environment of scientific experiments, reducing causal explanations of phenomena to the single variable under study. Likewise, the mathematics teacher is acculturated, to a great extent, to the idea that there is a single, right answer to mathematical relationships. Just as the technology teacher may have become interested in technology because of practice, science and mathematics teachers may have chosen their fields because of their affinity to the purity and orderliness of theory. Technology, with its multitude of “right” answers and often infinite numbers of variables that interact with one another, may simply not be of interest to them. Just as the technology teacher may be most interested in the hands on, the science teacher, and especially the mathematics teacher, may find “minds on” most attractive. This dichotomy is well articulated in C. P. Snow’s (1959) *The Two Cultures and the Scientific Revolution*.

The Challenge of Preparing Teachers for TSM Integration

Whether the disciplines of technology, science, and mathematics are totally integrated or the respective teachers simply integrate content within the classes they teach, a change in the professional education of teachers is essential. One of the main goals of universities is the generation of new knowledge. Virtually all reforms in educational practice have roots in higher education and the research that is generated there, yet the higher education “academy” is the most rigid and slowest component to change. There is even some irony that prevails. For example, the educational community has decried lecturing as one of the least effective methods of teaching, yet, it is almost the *sine qua non* of teaching in higher education. Likewise, and researchers in technology education promote new curricula, yet the courses they teach often do not reflect the ideas they are promoting to others.

Integration of subject matter at the elementary level comes almost naturally. With the typical “one teacher teaches all” model, the elementary teacher would almost have to make a concerted effort to avoid integration. As the grade level increases, however, integration becomes more difficult. Walls are formed around the disciplines. In higher education, the disciplines are separated into discrete buildings, both literally and figuratively. Often,

the faculty in a particular program have little idea about what the students learn in the courses they take outside of their own department. In addition, the content of these courses varies significantly across different sections of the same course and from one semester to another. These factors, as well as the sheer number of university faculty, make integration at the college level a massive challenge, indeed.

Even within colleges of education, there may be minimal knowledge among the faculty regarding what is learned in the professional courses their students take. The problem is no doubt worse in programs where the technology students are enrolled in one college (e.g., college of technology) while taking professional courses in another (e.g., college of education). The Holmes Group (1986) model of requiring a degree in the discipline in which a student expects to teach may also exacerbate the problem.

The structure, communication network, and magnitude of the higher education establishment provide sizable obstacles to even minimal approaches to integration of subject matter. Even if the discrete courses that prospective teachers take outside their discipline of choice are consistent over time and faculty are knowledgeable about their content, the void between the courses taken and the nature of how the discipline is taught in the public schools remains great. Yet, the void must be filled if the notion that “we teach as we are taught” is a truism.

Toward a Teacher Education Solution

If technology, science, and mathematics educators are committed to linking their disciplines more closely, then a change in the manner in which teachers are prepared must be forthcoming. Teachers of science and mathematics must have formal, relevant course work in technology. So-called “general technology” courses have been developed at the college level at several universities. Such courses have evolved from a variety of influences, including the Science, Technology, and Society (STS) movement, engineering programs that saw a need for the general public to become more informed about technological issues, social science faculty who recognized that technology is increasingly becoming a significant social force, and philanthropic foundations that recognized the pervasiveness of technology. Of course, technology teacher education programs have been involved in these efforts from the outset.

By and large, these general technology courses, even when offered by technology teacher education programs, have been studies *about* technology rather than studies *doing* technology. Perhaps this is a good first step toward the recognition of technology as an important area of study, but for teachers interested in integrating their discipline with technology, they fall well short

of the mark. What is needed are educational experiences in which *doing* technology is the *modus operandi*, but doing technology by itself is also insufficient. As Lux (1984) stated, "Practice is an essential but not sufficient characteristic of technology. That is, with the practice must go the theory of that practice, otherwise it is mere doodling. And theory without practice is mere intellectual exercise" (p. 18). To meet this goal, a commitment to a comprehensive, articulated, laboratory-based educational experience is needed. The model of delivering instruction through large group lectures, thereby generating significant student credit hours for the program with minimal resources, will not work. Science and mathematics teachers need to *do* technology in the same way that aspiring technology teachers do it in our programs.

Just as science and mathematics teachers need a quality experience in technology, the reverse is also true. As a first step, technology faculty must become knowledgeable about the specifics of the courses that their majors are required to take in science and mathematics. Conversely, the faculty in science and mathematics need to be informed about the course work that technology majors take. The resultant ability of the teacher to make instructional references to real world, technology problems can help make science and mathematics courses come alive, not only for technology students, but for all students.

Requirements need to be increased for science and mathematics course work, moving away from the apparent minimal standards that now prevail. The Undergraduate Studies Committee (1989) of the Council on Technology Teacher Education recommended that a minimum of 12 semester hours in science be completed by prospective technology teachers. As noted earlier, less than one fourth of recent graduates are meeting this standard. This committee also recommended that nine hours in mathematics and computer science be completed. Again, as noted earlier, an average of 7.6 credits were taken.

Fitting these courses into an already burgeoning curriculum is a challenge. The real challenge, however, may not be how to squeeze in the credits, but how to assure the quality of instruction. Often these courses are taught to very large classes of students and may not have a laboratory component. The instruction itself may be of low quality, with the courses often defaulting to inexperienced graduate students or mediocre professors. When this happens, it is not very conducive to motivating and exciting technology students about integrating mathematics and science into the technology courses they take, or to doing so once they begin their teaching careers. Despite these too-often-occurring realities, the need for technology teachers to have a solid background in science and mathematics is still essential for the future.

Professional methods courses should model what is expected of teachers in real school settings. Teams of technology, science, and mathematics majors should have the experience of planning and delivering lessons together. Even if the concerns about quality in science and mathematics instruction mentioned above cannot be resolved, such a cooperative experience is essential and may provide a salve for the wounds of the aspiring technology teacher who had a less than ideal experience with science and mathematics to that point. Finally, the integrated, team approach should extend to the student teaching experience, paralleling how team planning and implementation is supposed to work.

Perhaps it is time to consider a teacher preparation program that prepares an “integrated teacher”—a teacher who can take a group of students for an extended block of time and teach a course that truly integrates the three disciplines. In other words, prepare the prospective teacher from the outset as an integrator of the three disciplines. This would lead to teaching an integrated program simply because the instructor would not know any other way. No doubt there would be some serious tradeoffs and compromises, but it seems at least worthy of a feasibility study.

THE RESEARCH CHALLENGE

Research from a range of sources, many cited earlier in this chapter, suggests that further exploration of the notion of content integration is warranted. Notable among the research from the science and mathematics communities is the work of several individuals whose conclusions are in *direct* support of the idea of integrating technology education curricula with science and mathematics. Hamm (1992) identified a series of steps that should be taken to further the cause of science and mathematics education. These recommended steps cry out for a technology education laboratory in which to implement her vision:

1. Improve the teaching of science, mathematics, and technology . . . [by] providing students with active hands-on experience, placing emphasis on students' curiosity and creativity, and frequently using a student team approach to learning (Adams & Hamm, 1990).
2. Attend to the importance of students in the learning process. Students need to be placed in situations where they develop and create their own science understandings, connect concepts with personal meanings, and put ideas together for themselves.
3. Incorporate innovative and alternative teaching and learning strategies. Classrooms should be organized so that small mixed-ability

groups are a forum for mathematics/science discussions, discovery, creativity, and connections to other subjects.

4. Develop new curriculum models. To achieve the goals of scientific literacy, the curricula must be changed to reduce the amount of material covered and emphasize a thematic approach. There is a need to focus on the connections among the various disciplines of science, mathematics, technology and build integrated understandings. (pp. 7–8)

W. M. Roth, a high school physics teacher, began to recognize the role that physical apparatus could play in the learning of mathematics and science. He conducted case studies of his high school physics students. The activities he describes are similar to those developed as technology, science, mathematics integration activities:

The photo gate, the cart, and the springs which the students used in their experiment were part of the setting they controlled and which, in this sense, was like the real world. They recorded data, made charts, used MathCAD, submitted a report. . . . As Michael described the motion of the cart, he made connections between several levels of conceptual abstraction. . . . Finally, the apparatus used, a relatively easily observed physical system which can be replayed in slow motion, played a major role for Michael's construction of physics and mathematics knowledge. (1993, p. 115)

Roth's research led him to suggest the need for substantial additional research in this area. One such conclusion indicates the need for an entire program of research on the viability of teaching scientific and mathematical principles using concrete apparatus as the stimuli. Research of this nature would help to reinforce or refute the pedagogical approach underlying the integration of technology education with science and mathematics in our schools:

The implications for research are clear. First, a number of concrete apparatus should be identified which have to satisfy two conditions. These apparatus should lend themselves to anchor sound curricular units for the integration of science and mathematics, and they should be of a complexity which facilitates the construction of meaning rather than stifling it. Then, research should be conducted to investigate the construction of meaning in classroom settings in which science and mathematics teaching and learning is systematically organized around these apparatus. Finally, research should be conducted to determine if

and how such apparatus-centered curricula help establish classroom communities of meaning makers. (1993, p. 121)

Roth's conclusions help build a rationale for the sort of science and mathematics problems that are routinely encountered in technological problem-solving activities. He implies that the technological problem-solving activities that have customarily been used in technology education for the past decade are a perfect metaphor for the study of science and mathematics principles. These technological problem-solving activities, however, take Roth's notion to another level, since they allow students to design, construct, and evaluate their own "apparati" rather than those supplied somewhat artificially by the teacher. As Roth states:

The results of this and other studies (e.g., Greeno, 1988) make it quite clear that students' interactions with physical apparati and events allow students to construct multiple representations and serve as anchors of both for conceptual science and mathematics knowledge. These apparati can be of a simple nature as Greeno's (1988) pulley crank system to study linear functions or a balance beam to study ratios. (1993, p. 121)

The idea of integrating technology, science, and mathematics curricula makes sense from a variety of perspectives. There is growing support from all three school disciplines involved. Moreover, the nature of learning promoted by this approach is beautifully aligned with the Piagetian, inquiry based, and constructivist learning theories currently under investigation throughout the educational arena. As with other movements in education, however, it would be misleading to suggest that all current efforts are solidly founded in empirical research. There is much work yet to be done in this regard.

CONCLUSION

More than at any time before in the history of education, the stage is now set for a closer working relationship among technology, science, and mathematics. A number of reports from very credible and politically influential sources have recognized the existence of technology and its vital importance in the education of America's citizenry. Funding opportunities are becoming increasingly available to support collaboration among the three disciplines. The concept of teaming among teachers of various subjects is being promoted and implemented in the schools, especially at the middle school level. Though insufficient at the present time, research evidence is

mounting to show that technology education, with its hands-on, practical problem-solving approach, can increase students' interest in science and mathematics and can likely increase their understanding as well.

Changes are needed in the structure of schools if integration is to be realized. Technology teachers must be included on the same planning team as are the science and mathematics teachers. Ideally, the school schedule should be overhauled to facilitate integration. At the pre-service level, technology teachers must have a solid, quality experience in science and mathematics—one that stimulates the prospective teacher and exemplifies the value and importance of these disciplines. Prospective science and mathematics teachers, likewise, need a quality experience with hands-on technology education.

Beyond the benefits of learning in an integrative manner, there are clear benefits that integration with math and science would provide technology education. Most important is the potential to establish technology education as an essential educational experience for everyone. In this way it would attain the general education goal to which the field has aspired since its inception.

There are also potential threats, as well as benefits associated with integration. Perhaps most significant is the possibility that technology will remain educationally important, but that its instruction will be delivered by the math and science teachers. Though this scenario is possible, there are at least three arguments against it. First, the science and mathematics curricula are operating in a deficit, already, in terms of the instructional time needed to cover the prescribed content. Time and flexibility are major contributions that the technology curriculum can make. Second, the technology laboratory is a facility unlike any other in the school, specifically designed to teach technology. The equipment and materials in the technology lab enable the students to solve real, technological problems with real tools—not simply the cognitive problems in the textbook or those solved with cardboard, balsa wood, razor knives, and glue. Students realize an experience they may never again have in their entire lives. Finally, the technology teacher has unique, specialized qualifications to make this happen. The content and method that technology teachers bring to their classes are very rich and adaptable to an integrated approach to instruction. The ability to supervise many different problem-solving activities concurrently in a technology lab is a talent that should not be underestimated, and most math and science teachers have had little or no experience with this approach.

It is possible to conceive of a technology education program that could be delivered without the tools, materials, and expertise currently used by technology teachers. Such a curriculum might be taught by science or even social studies teachers. This, however, could never begin to provide the rich

learning opportunities that are afforded by the environment created in exemplary technology education labs as we know them today.

Though one could argue that discipline integration and the teaming of teachers is but another wave of educational rhetoric that will wash the shore, the pervasiveness of interdisciplinary instruction in actual practice, particularly at the middle school level, causes even the staunchest pessimist to give this approach a second look. While there are numerous logistic barriers that may be used as an excuse not to integrate these three disciplines, surely students would benefit from seeing the content of each in this larger, real world context.

REFERENCES

- Adams, D., & Hamm, M. (1990). *Cooperative learning: Critical thinking and collaboration across the curriculum*. Springfield, IL: C. Thomas.
- American Association for the Advancement of Science. (1989). *Science for all Americans: A Project 2061 report on literacy goals in science, mathematics, and technology*. Washington, DC: Author.
- Balka, D. S. (1983). Mathematics manipulatives in a pre-vocational program: Teacher inservice and classroom research. (ERIC Document Reproduction Service No. ED 237 739)
- Bernhardt, L. J., Jr. & McHaney, L. J. (1992). *Space simulation*. Albany, NY: Delmar.
- Boyer, E. L. (1983). *High school: A report on secondary education in America*. New York: Harper Colophon.
- Bredderman, T. (1982). What research says: Activity science—The evidence shows it matters. *Science and Children*, 20(1), 39–41.
- Bredderman, T. (1985). Laboratory programs for elementary school science: A meta-analysis of effects on learning. *Science Education*, 69, 577–591.
- Brooks, R. C. (1988). *Improving student science achievement in grades 4–6 through hands-on materials and concept verbalization*. (ERIC Document Reproduction Service No. ED 317 430)
- Brusic, S. A. (1991). Determining effects on fifth-grade students' achievement and curiosity when a technology education activity is integrated with a unit in science. (Doctoral dissertation, Virginia Polytechnic Institute and State University, 1991). *Dissertation Abstracts International*, 52(9), 3204A.
- Brusic, S. A., & Barnes, J. L. (1992). *Mission 21: Teacher's Resource Book Grades 5–6*. Albany, NY: Delmar.
- Bybee, R. W. (1991). Science-technology-society in science curriculum. The policy-practice gap. *Theory Into Practice*. 30(4), 294–302.
- Canny, M. C. (1984). The relationship of manipulative materials to achievement in three areas of fourth-grade mathematics. (Doctoral dissertation, Virginia Polytechnic Institute & State University, *Dissertation Abstracts International*, 45. 775A.

- Champion, G. (1966). The interrelationship of industrial arts with science in the elementary school (Doctoral dissertation, University of Maryland, 1965). *Dissertation Abstracts International*, 26(11), 6543A.
- Cohen, H. G. (1992). Two teaching strategies: Their effectiveness with students of varying cognitive abilities. *School Science and Mathematics*, 92(3), 126–132.
- Cotton, K., & Savard, W. (1992). *Intermediate level mathematics and science instruction: Research synthesis*. Portland, OR: Northwest Regional Educational Lab. (ERIC Document Reproduction Service No. ED 222 366)
- DeVore, P. W. (1987). Science and technology: An analysis of meaning. *Journal of Epsilon Pi Tau*, 13(1), 2–9.
- Downs, W. A. (1969). The effect of constructional activities upon the achievement in the areas of science and mathematics at the fifth grade level. (Doctoral dissertation, University of Missouri-Columbia, 1968). *Dissertation Abstracts International*, 29(8), 2542A.
- Dugger, W. E., Miller, C. D., Bame, E. A., Pinder, C. A., Giles, M. B., Young, L. H., & Dixon, J. D. (1980). *Report of the survey data*. Blacksburg, VA: Standards for Industrial Arts Programs Project, Virginia Polytechnic Institute and State University.
- Exxon Education Foundation. (1984). *Science education in the United States: Essential steps for achieving fundamental improvement*. New York: The Foundation.
- Finch, C. R.; Schmidt, B. J.; Oliver, J. D.; Yu, Kuang-Chao; and Wills, A. (1992). *Course-taking patterns of vocational teacher education baccalaureate recipients: Teacher preparation, general education, and teaching content area studies*. Berkeley: National Center for Research in Vocational Education, University of California at Berkeley.
- Gallagher, J. J. (1971). A broader base for science teaching. *Science Education*. 55(3), 329–338.
- Glasson, G. E. (1989). The effects of hands-on and teacher demonstration laboratory methods on science achievement in relation to reasoning ability and prior knowledge. *Journal of Research in Science Teaching*, 26(2), 121–131.
- Greeno, J. G. (1988, November). *Situated activities of learning and knowing mathematics*. Paper presented at the annual meeting of the North

American Chapter of the International Group for Psychology of Mathematics Education, DeKalb, IL.

- Hamm, M. (1992). Achieving scientific literacy through a curriculum connected with mathematics and technology. *School Science and Mathematics*, 92(1), 6–9.
- Haury, D. L., & Rillero, P. (1992). *Hands-on approaches to science teaching: Questions and answers from the field and research*. Columbus, OH: ERIC Clearinghouse for Science, Mathematics, and Environmental Education. (ERIC Document Reproduction Service No. ED 349 185)
- Hoffman, L. (1989). *Development of students' interest in physics in relation to characteristics of instruction and out-of-school conditions*. Paper presented at the Annual Meeting of the American Educational Research Association. (ERIC Document Reproduction Service No. ED 310 918)
- Holmes Group. (1986). *Tomorrow's Teachers: A report of the Holmes Group*. East Lansing, MI: Holmes Group.
- International Association for the Evaluation of Educational Achievements. (1987). *The underachieving curriculum: A national report on the second international mathematics study*. Champaign, IL: Stipes Publishing.
- International Association for the Evaluation of Educational Achievements. (1988). *Science achievement in seventeen countries*. Oxford, UK: Pergamon Press.
- Jaus, H. H. (1977). Activity-oriented science: Is it really that good? *Science and Children*, 14(7), 26–27.
- Johnson, J. (1993, July). Why technology? *Phillips Focus* (Phillips Petroleum newsletter).
- Johnson, J. R. (1989). *Technology: Report of the Project 2061 Phase I Technology Panel*. Washington, DC: American Association for the Advancement of Science.
- Kipfinger, M. E. (1990). Comparison of two methods of teaching geometry at the middle school level as influenced by the Van Hiele model. (Masters thesis, San Jose State University). *Masters Abstracts International*, 28/04. 488.
- Korwin, A. R., & Jones, R. E. (1990). Do hands-on, technology-based activities enhance learning by reinforcing cognitive knowledge and retention? *Journal of Technology Education*, 1(2), 26–33.

- Kowal, J. J. (1985). The effects of constructional activities incorporating the locus of control construct on motivation in fourth grade students. (Doctoral dissertation, The Ohio State University, 1984). *Dissertation Abstracts International*, 45(8), 2421A.
- Kranzberg, M. (1991). Science-technology-society: It's as simple as xyz. *Theory Into Practice*, 30(4), 134–241.
- Kruglak, H. (1953). Achievement of physics students with and without laboratory work. *American Journal of Physics*, 21, 14–16.
- Kyle, W. C., Bonnstetter, R. J., Gadsden, T., & Shymansky, J. A. (1988). What research says about hands-on science. *Science and Children*, 23(2), 39–41.
- Kyle, W. C., Bonnstetter, R. J., McCloskey, J., & Fults, B. A. (1985). What research says: Science through discovery – students love it. *Science and Children*, 23(2), 39–41.
- Langbort, C., & Thompson, V. H. (1985). *Building success in math*. Belmont, CA: Wadsworth.
- LaPorte, J. E., & Sanders, M. E. (1992, March). *Technology/science/mathematics activities for the middle school*. A resource prepared for preconference workshop at the Annual Conference of the International Technology Education Association, Minneapolis, MN.
- LaPorte, J. E., & Sanders, M. E. (1993). The T/S/M Integration Project: Integrating technology, science, and mathematics in the middle school. *The Technology Teacher*, 52(6), 17–21.
- Lenoir, P. (1989). The effects of manipulatives in mathematics instruction in grades K–college: A meta-analysis. (Doctoral dissertation, North Carolina State University). *Dissertation Abstracts International*. 50/05. 1241A.
- Loepp, F. (1991). *Integrated math, science, and technology*. Unpublished project proposal submitted to the National Science Foundation. Normal, IL: Illinois State University.
- Logan, N. (1973). The effect of constructional activity upon achievement at the third grade level (Doctoral dissertation, University of Missouri-Columbia, 1973). *Dissertation Abstracts International*, 35(2), 942A.
- Lux, D. G. (1984). Science and technology: A new alliance. *Journal of Epsilon Pi Tau*, 10(1), 16–21.

- Lynch, R. L. (1990). *A national database on vocational teacher education*. Berkeley: National Center for Research in Vocational Education, University of California at Berkeley.
- Maley, D. (1973). *Maryland plan: The study of industry and technology in the junior high school*. New York: Bruce.
- Maley, D. (1984). *Math/Science/Technology Projects for the Technology Teacher*. Reston, VA: International Technology Education Association.
- Mattheis, F. E., & Nakayama, G. (1988). *Effects of a laboratory-centered inquiry on laboratory skills, science process skills, and understanding of science knowledge in middle grade students*. (ERIC Document Reproduction Service No. ED 307 148)
- McCoy, L. P. (1989, February). Perceptual preferences of mathematically deficient elementary students: Implications for instruction. Paper presented at the Annual Meeting of the Eastern Educational Research Association, Savannah, GA. (ERIC Document Reproduction Service No. ED 305 379)
- Mechling, K. R., & Oliver, D. L. (1983). Activities, not textbooks: What research says about science programs. *Principal*, 62(4), 41-43.
- Meira, L. R. (1992). Explorations of mathematical sense-making: An activity-oriented view of children's use and design of material displays (manipulatives). (Doctoral dissertation, University of California, Berkeley). *Dissertation Abstracts International*. 53/06. 1833A.
- Morey, M. K. (1990). Status of science education in Illinois elementary schools, 1987. *Journal of Research in Science Teaching*, 90(4), 387-397.
- National Assessment of Educational Progress. (1989). *Learning by doing*. Princeton, NJ: Educational Testing Service.
- National Council of Teachers of Mathematics. (1989). *Curriculum and evaluation standards for school mathematics*. Reston, VA: Author.
- National Research Council. (1992a, October). *National science education standards: A working paper of the National Committee on Science Education Standards and Assessment*. Washington, DC: Author.
- National Research Council. (1992b, November). *National science education standards: A sampler*. Washington, DC: Author.

- National Research Council. (1993a, February). *National science education standards: An enhanced sampler*. Washington, DC: Author.
- National Research Council. (1993b, July). *National science education standards: July '93 progress report*. Washington, DC: Author.
- National Science Board Commission on Precollege Education in Mathematics, Science, and Technology. (1983). *Educating Americans for the 21st century: A report to the American people and the National Science Board*. Washington, DC: National Science Foundation.
- National Science Foundation and the U.S. Department of Education. (1980). *Science and Engineering Education for the 1980s and Beyond*. Washington, DC: The Foundation.
- National Science Teachers Association. (1992). *Content core: A guide for curriculum designers*. Washington, DC: Author.
- Pershern, R. (1967). The effect of industrial arts activities on science achievement and pupil attitudes in the upper elementary grades. (Unpublished dissertation, Texas A&M University, 1966). *Dissertation Abstracts International*, 28(2), p. 549
- Physical Science Study Committee (1960). *Physics*. Boston: Heath.
- Prigge, G. R. (1978, November). The differential effects of the use of manipulative aids on the learning of geometric concepts by elementary school children. *Journal of Research in Mathematics Education*, 9, 361–367.
- Roth, W. M. (1993). Problem-centered learning for the integration of mathematics and science in a constructivist laboratory: A case study. *School Science & Mathematics*, 93(3), 13–122.
- Rowland, P. M. (1990). *Using science activities to internalize locus of control and influence attitudes towards science*. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Atlanta. (ERIC Document Reproduction Service No. ED 325 333)
- Roy, R. (1989). Relationship of technology to science and the teaching of technology. *Journal of Technology Education*, 1(2), 5–18.
- Saunders, W. L., & Shepardson, D. (1984). *A comparison of concrete and formal science instruction upon science achievement and reasoning ability of sixth grade students*. Paper presented at the annual meeting of the

- National Association for Research in Science Teaching, New Orleans. (ERIC Document Reproduction Service No. ED 244 797)
- Savage, E. R. (1991). A rationale for bio-related technology. *Journal of Epsilon Pi Tau*, 17(2), 59–62.
- Scarborough, J. D. (1993a). Phys-Ma-Tech: Integrated models for teachers. *The Technology Teacher*. 52(5), 26–30.
- Scarborough, J. D. (1993b). Phys-Ma-Tech: Operating strategies, barriers and attitudes. *The Technology Teacher*. 52(6), 35–38.
- Shymansky, J. A., Kyle, W. C., & Alport, J. M. (1982). How effective were the hands-on science programs of yesterday? *Science and Children*, 20(3), 14–15.
- Sigda, E. J. (1983). The development and evaluation of a method for teaching basic multiplication combinations, array translation, and operation identification with third grade students. (Doctoral dissertation, Temple University). *Dissertation Abstracts International*. 44/06. 1717A.
- Simon, P. J. (1991). Descriptive study of a third and fourth-grade manipulative-based mathematics program. (Doctoral dissertation, Lehigh University). *Dissertation Abstracts International*. 52/05. 1674A.
- Snow, C. P. (1959). *The two cultures and the scientific revolution*. NY: Cambridge University Press.
- Tilgner, P. J. (1990). Avoiding science in the elementary school. *Science Education*, 74(4), 421–431.
- Todd, R. (1992). *Project Update*. Unpublished project proposal submitted to the National Science Foundation. Philadelphia: Drexel University.
- Tooke, D. J., Hyatt, B., Leigh, M., Snyder, B., & Borda, T. (1992, November). Why aren't manipulatives used in every middle school mathematics classroom? *Middle School Journal*. pp. 61–62.
- Towers, E. R., Lux, D. G., & Ray, W. E. (1966). *A rationale and structure for industrial arts subject matter*. The Ohio State University Research Foundation.
- Undergraduate Studies Committee. (1989). Elements and structure for a model undergraduate technology teacher education program. Reston, VA: Council on Technology Teacher Education, International Technology Education Association.

- Vars, G. F. (1987). *Interdisciplinary Teaching in the Middle Grades*. Columbus, OH: National Middle School Association.
- Weiss, I. R. (1987). *Report of the 1985–86 National Survey of Science and Mathematics Education*. (ERIC Document Reproduction Service No. ED 292 620)
- White, R. T. (1979). Relevance of practical work to comprehension of physics. *Physics Education* (Australia), 14, 384–387.
- Wicklein, R., Hammer, D., Balistreri, J., DeVore, P., Scherr, S., Boudreau, W., & Wright, J. (1991). Technology education demonstration projects. *The Technology Teacher*, 51(3), 3–8.
- Yager, R. (1988a). S/T/S produced superior student performance. *Chataqua Notes*, 3(5), 1–3.
- Yager, R. (1988b). *Assessing the impact of the Iowa Honors Workshop on science teachers and students: A final report for NSF*. Iowa City, IA: University of Iowa, Science Education Center.
- Yager, R., Blunck, S., Binadji, A., McComas, W., & Penick, J. (1988). *Assessing impact of S/T/S instruction in 4–9 science in five domains*. Unpublished manuscript, University of Iowa, Science Education Center, Iowa City.