

The T/S/M Integration Project

Integrating Technology, Science, and Mathematics in the Middle School

James LaPorte & Mark Sanders



Technological knowledge has existed far longer than scientific knowledge. Prior to the 1950s, the majority of the technological inventions and innovations did not rely upon scientific theory for their development. In the future, however, scientific theory will increasingly undergird technological development. As a result technology educators will need to incorporate scientific and mathematical principles into their curricula.

This is not a new idea. Sredl (1967) credits Donald Maley, Professor Emeritus at the University of Maryland, as a pioneer in the application of science and mathematics to technology education (then industrial arts), promoting such application as early as the 1950s. Maley's work in this endeavor continues today. In 1960, the State of California published two guides that outlined how science and mathematics could be integrated into industrial arts (California Department of Education).

What is new is the fact that national reports are recognizing technology education as an essential element in the education of our citizenry. Virtually all of the national reports of the 1980s on the status of education such as *A Nation at Risk: The Imperative for Educational Reform* (National Commission on Excellence in Education, 1983) and *Science and Engineering Education for the 1980s*

and Beyond (National Science Foundation and U.S. Department of Education, 1980) identified the need for new approaches to science and mathematics education. The growing public awareness of these issues and research findings such as those cited in *Science Achievement in Seventeen Countries: A Preliminary Report* (International Association for Evaluation of Educational Achievement, 1988) have helped foster support for change in science and mathematics curricula.

In the late 1980s, the American Association for the Advancement of Science sponsored "Project 2061" and out of this project came *Science for All Americans* (American Association for the Advancement of Science, 1989), a concise blueprint for science education for the 21st century. In a related effort, Project 2061 produced a set of five more specific panel reports on science, mathematics and technology education (*Biological and Health Sciences*, 1989a; *Mathematics*, 1989b; *Physical and Information Sciences and Engineering*, 1989c; *Social and Behavioral Sciences*, 1989d; and *Technology*, 1989f). Concurrently, the National Council of Teachers of Mathematics released *Curriculum and Evaluation Standards for School Mathematics* (National Council of Teachers of Mathematics, 1989), and followed that with *Professional Standards for Teaching Mathematics* (National Council of Teachers of Mathematics, 1991).

Taken together, these reports signal a monumental effort in the reform of science and mathematics education. Not since the aftermath of the Sputnik launch in 1957 has America taken so seriously its commitment to science and mathematics education.

In addition, there is a growing awareness of the important role of technology as it relates to both science and mathematics. Recently, the National Science Foundation has begun to include technology education in its funding scheme. The *Technology/Science/Mathematics Integration Project*, described in this article, funded by the National Science Foundation, is designed to integrate technology with mathematics and science at the middle school level.

A Brief Rationale and Guiding Principles

Theory and Practice

Science and mathematics pedagogy has been strong in theory but weak in practice. In recent years there has been an increased emphasis in hands-on activities to lead learners into curiosity about the natural world. But, these hands-on activities generally focus upon revalidating known scientific laws and principles. The application of scientific knowledge to the solution of practical problems has often been limited to imaginary textbook examples, often called "story problems." As a result, many students do not find science and mathematics interesting.

Technology education, on the other hand, has been strong in practice but weak in theory. Though there has been increased emphasis on problem solving in the field, the knowledge that is applied to the solution of problems is often limited to what the student had when s/he enrolled in the course. For example, the CO₂-powered car, originally popularized by the Industrial Arts Curriculum Project (1971), remains as a very motivating activity for students. Regional and national races of the cars are held regularly. Unfortunately, the reason why some cars win and some lose is often a mystery to the students and to their teachers as well. The same may be said about model bridges, rubber band-powered vehicles, and other contemporary activities.

Yet these activities offer rich opportunities to apply mathematics and science principles, resulting in a truly

integrated experience for the learners. During the past decade, technology teachers have capitalized on the interest and motivation that technological problem solving activities provide. For the science and mathematics teachers, too, technological problem solving activities may provide a practical, meaningful, and motivating learning context. This idea is especially robust if the solution of a technological problem *depends* upon a knowledge of science and mathematics. That is the idea behind the *T/S/M Integration Activities* developed by the Project.

Technology Education as General Education

The link between technology, mathematics, and science provides a number of advantages to the technology education profession. Historically, technology education (and its predecessor, industrial arts) has subscribed to the ideal of general education—education that is essential and beneficial to all (regardless of career aspirations). The name change from industrial arts to technology education and the resultant shift in philosophy have even more clearly placed technology education in the general education arena. However, this ideal has not yet been fully realized because technology education is an elective subject in most schools and the general population often associates it with job preparation. Teaming technology teachers with mathematics and science teachers and thus placing technology education in the mainstream of the general education portion of the curriculum can facilitate the realization of this ideal.

Require Minimal School Restructuring

At the outset, we decided that the success of the *T/S/M Integration Project* should not depend completely upon a major structural change in the organization of the school nor a dramatic shift in the behavior of the teachers involved. Such changes reduce the likelihood of success as evidenced by the work of classical change theorists such as Rogers (1971) and Havelock (1973). To avoid a major change in the school schedule, only students that had elected to enroll in a technology course were full participants in the activities. At the same time, the technological problem was to serve as unifying thread for instruction in the mathematics and science classes. Thus, all students potentially benefit from the new approach even if they are not enrolled in technology education. What's more,

exposing science and mathematics students to the exciting activities used in technology education may well have a positive effect on technology enrollments in the future.

The activities developed are not intended to be a "curriculum" in the full sense of the word. They are intended to complement what goes on in the technology, science, and math programs. Therefore, they are designed to be used in a variety of ways and in a variety of settings.

Let Science Provide Direction for the Activities

The science curriculum is more prescriptive and structured than the technology curriculum. We therefore decided to let science content serve as the basis for the activities that we developed. In other words, science concepts were identified and then technological problems were developed and correlated to these concepts. Mathematics concepts and principles fit naturally into both technological problem-solving and science, so mathematics activities were easily adapted to fit within this overall context.

Drawing ideas from the science curriculum to serve as a basis for these activities in no way undermines the current technology education curriculum. It simply guarantees the activities developed have a direct relationship to the existing science curriculum. As it turns out, all of the activities developed fit logically under the technology education organizers of communication, construction, manufacturing, and transportation. What's more, variations of many of the activities are already being used in technology education programs already, albeit *without* correlation to science and mathematics content.

Design Under Constraint

The technological problem solving activity provides the common thread among the three disciplines. All of the activities were developed with the notion of "design under constraint" in mind. This approach was perhaps first used in the "design briefs" developed for Design and Technology curricula in Great Britain. Rather than posing a completely open-ended technological problem, some constraints are imposed. In practice, these constraints may be indicated by size or material limitations or performance standards. The ubiquitous "mousetrap car," for example, is constrained by a requirement that it be powered by a mousetrap (material limitation) and often must travel a certain distance (performance standard). "Design under constraint" works well from a teacher

management standpoint. It provides some degree of focus for the student activity without overly constraining it to a "lock-step" approach common in the "water-pump lamp" era of industrial arts. The approach also has many parallels to what a practicing engineer does.

Project Activities and Outcomes

Review of the Literature

Literature relating to the *T/S/M*

Integration Project goes far deeper than the national reports of the 1980s. While those reports are a reaction to the state of disrepair of science and mathematics education, surprisingly little research is cited to substantiate the bold new directions they espouse. The *T/S/M Integration Project* has begun the sizable task of reviewing and synthesizing a diverse body of literature relating the disciplines of science, math, and technology education. In addition to the research in each of these three academic disciplines, cognitive learning and assessment research are hugely relevant.

Surprisingly little research has been conducted on the role of psychomotor/technology-based activities in reinforcing cognitive learning at the middle school level. While this relationship is well established at the pre-school and early childhood levels of education, the same cannot be said for the pre-adolescent years. While technology teachers are quick to tell personal success stories of the many things their students learn above and beyond the psychomotor domain, there is a dearth of research conducted to substantiate this claim. And because mathematics and science education have not traditionally supported their instruction with hands-on technology-based activities, these fields have conducted virtually no research in this arena. The work done in "hands-on science" should not be confused with that of "hands-on technology," since the former relates largely to the use of experimentation (applying the scientific method) in the science laboratory while the latter refers to the construction of technological solutions (applying the technological method).

New Technology/Science/Mathematics Curriculum Materials

First and foremost, the *T/S/M Integration Project* will produce a set of activities that may be shared by technology, science, and mathematics teachers. These integrated activities are designed to build upon the natural overlap among these three curricula. The activities will be published upon completion of the project in early 1994.

Integration of Technology, Science, and Mathematics Curricula

One of the obvious outcomes of bringing technology, science, and mathematics

teachers together to develop and implement curriculum materials is to foster integration of the three. While there are obvious areas of overlap, these three subjects have traditionally been taught in isolation of each other. While the middle school movement is predicated on team teaching to integrate the various "academic" disciplines, this has ironically been achieved at the expense of the "non-academic" subjects. Sadly, technology teachers are typically systematically eliminated from the teams, since planning time for the teaching teams is scheduled by shipping students off to the "related arts," a misnomer for the elective subjects in the schools.

The *T/S/M Integration Project* provides a corollary to the middle school teaming strategy by involving the technology teacher in team planning. The simple act of consciously coordinating technology education activities with mathematics and science instruction can and should be used to reinforce the learning that takes place in the mathematics and science classrooms. Once this is accomplished, then movement towards a higher level of integration among the subjects may begin.

Application of Mathematics and Science Principles to Solve "Real World" Problems

A recurring criticism of mathematics and science curricula has been the removal of their subject matter from the context of the real world. Students have studied mathematics and science rather abstractly, and then found it difficult to apply the principles they learned to real world settings. Technological problem solving, on the other hand, is predicated on the application of ideas and understandings to create very practical solutions. As problem solving activities have developed in technology education in the 1980s, however, there has been little systematic effort to require mathematics and science application in the solution of problems. That is, technology education problem solving activities have required students to solve practical problems, but they may not have employed mathematics and science in doing so. If they did, it was accidental rather than premeditated. The *T/S/M Integration Project* is designing activities with mathematics and science application as the primary objective. Students will consciously begin to see mathematics and science as problem solving tools, much the same way as they routinely employ cutting and shaping tools in the technology curriculum.

Developing T/S/M Integration Activities

The development of activities that integrate technology, science and mathematics curricula is the primary objective of the *T/S/M Integration Project*. The process of doing so will continue throughout the duration of the project, and includes the following phases:

1. Review of related literature
2. Develop "checklist" for *T/S/M Integration Activities*
3. Initial activity development by middle school teacher teams
4. "Fleshing out" of activities by a writing team
5. Statewide field test and evaluation of the activities
6. Revision of activities
7. Development of teacher in-service materials
8. National field test and evaluation of the activities
9. Further revision of activities
10. Dissemination of activities

When the project began, we were not really certain what constituted an integrated technology/science/mathematics activity. Based upon the review of literature, we established a set of guidelines for developing *T/S/M Integration Activities*. *Each activity idea was subjected to the following "checklist":*

1. Is the activity directly linked to a science concept?
2. Does it present a practical problem to be solved?
3. Does it focus on the human-made world rather than the natural world?
4. Does it involve "design under constraint?"
5. Does it require the application of mathematics and science principles in the design, execution and/or evaluation phases?
6. Does it involve manipulating tools, materials, and equipment to produce a real operational solution to a problem?
7. Does it allow for a multitude of "right" solutions?
8. Does it involve planning at the outset, evaluation at the conclusion, and documentation throughout?
9. Is it "do-able" by the students for whom it is intended?
10. Can it be managed by the teachers involved?

The Project identified six Virginia middle school teams, each consisting of a technology, math, and science teacher to assist with the development and field testing of the activities. A "kick-off" meeting was

held in May, 1991 to orient these six teams and their principals to the project. This provided them about a month's time to think about *T/S/M Integration Activities* prior to beginning their development efforts. In June 1991, five of the six teams attended a one-week activity development workshop conducted at Virginia Tech. Armed with the "checklist" described above and a wide range of resources, the teams developed the basic structure for 16 *T/S/M Integration Activities* during that workshop (See Table I). Many of the activity ideas the teacher teams settled upon may not appear new to technology teachers at first glance. This concerned us, initially. We came to realize, however, that what was new about these activities was not necessarily the technology component, but the integration of the technology component with the science and mathematics components. That is, while some of the ideas they generated had been done in the technology laboratory, they were, for the most part, completely new to the science and mathematics teachers. The "new" part is the extensive development the project has done with regard to the science and mathematics component, and the integration of those principles with the technological problem-solving activity.

The science and mathematics teachers were very excited about the activities—even those that technology teachers have worked with in the past (such as the mousetrap car or model rocket). To them, these were new activities. Moreover, since technology teachers will be somewhat comfortable with certain of these activities, there is a considerably greater likelihood they will gain acceptance among technology teachers than those activities that are completely new and different.

Throughout the remainder of the summer, the Project staff worked to "flesh out" these activities. The activities were put into a standard format and the technology, science, and mathematics teaching components were enhanced considerably. Former technology, science, and mathematics teachers were employed by the project to fully develop each component of these activities. Thus, a typical *T/S/M Integration Activity* includes a one page "Problem-Solving Brief" followed by an overview of the Activity that describes the role of each teacher, the instructional sequence and a list of resources. This is followed by 10-20 pages for each of the technology, science, and mathematics components, which include basic information, specific teaching strategies, resources, and helpful hints to the teacher.

These activities were field tested in Virginia middle schools during the

T/S/M Activities Developed in Summer Workshop

Alarming Container

Design and construct a container that will sound an alert when opened. Technology: electrical circuits, wiring, switches, relays. Science: electricity, insulators and conductors, Ohm's Law, sound. Math: calculations with Ohm's law, volume, cost estimation.

Automobile Graveyard

Design and construct an electromagnetic device to move junk automobiles. Technology: electricity, mechanisms, simple machines. Science: electromagnetism, simple machines. Math: multiplication, graphing, and proportion.

Cabin Insulation

Design and construct an insulating panel from recycled materials. Technology: basic tools, thermal resistance, energy conservation. Science: heat, heat transfer, properties of materials. Math: equation manipulation, graphing, linear and non-linear relationships.

The Can Crusher

Design and construct a can crushing device. Technology: tools and machines, mechanisms. Science: simple machines, mechanical advantage, efficiency. Math: efficiency, mechanical advantage.

Capture the Wind

Design and construct a device that produces electricity from wind. Technology: alternative energy, energy generation, energy conversion. Science: basic electricity, voltage, resistance, current, geology, meteorology. Math: surface area, graphing, unit conversion.

Composite Beam

Design and construct a concrete beam reinforced with recycled materials. Technology: construction, strength of materials, composites, material testing. Science: exothermic chemical reactions, stress and strain, compression and tension. Math: area, volume, formulas, proportion, graphing.

Driver Protection

Design and construct an impact control/system for a vehicle. Technology: materials, ergonomics, energy absorption. Science: Newton's Three Laws of Motion. Math: acceleration, graphing, relationships between variables.

MagLev Vehicle

Design and construct a magnetically-levitated vehicle powered by an electric motor. Technology: electrical wiring, fixed path transportation. Science: simple electricity, conductivity, electromagnetism, properties of materials. Math: time, rate, distance.

The Plant Plant

Design and construct a hydroponic production system. Technology: hydroponic production systems. Science: plant nutrition and growth, scientific method, experimentation. Math: statistics, collecting and organizing data.

Pollution Free Vehicle

Design and construct a vehicle powered by a non-polluting energy source. Technology: power transmission, basic tools and machines. Science: potential and kinetic energy, simple machines. Math: radius, diameter, circumference, proportion.

The Power Boat

Design and construct a safe toy power boat. Technology: energy conversion, boat hull design, drag. Science: buoyancy, surface tension. Math: calculating displacement and volume.

Robotic Transfer System

Design and construct a hydraulic-powered system to transfer hazardous materials from one point to another. Technology: basic tools and machines, fluid power transmission, fluid power circuits, controlled motion. Science: Bernoulli's Principle, Boyle's Law, Pascal's Law. Math: relationships between variables.

Rocket Payload

Design, build, and launch a model rocket that deploys an object to aid in measuring

wind speed and direction. Technology: rocket design, principles of flight, guidance and tracking, altitude and wind speed measurement. Science: Newton's Laws of Motion, Boyle's Law. Math: multiplication, trigonometry, graphing, angles.

Solar Cooker

Design and construct a solar cooking system. Technology: layout practices, basic tools, sheetmetal, manufacturing, alternative energy. Science: properties of light, mirrors and lenses, solar incidence. Math: conic sections, geometric construction, cartesian coordinate system.

The Sound of Music

Design and construct a device that produces a prescribed sound frequency. Technology: tools and equipment, specifications, product testing, sound transmission, amplification, and measurement. Science: vibration, wave theory, reflection, refraction. Math: frequency, time, rate, distance.

Weather Watch

Design and construct a weather station. Technology: system theory, electricity, electronics, computer input. Science: meteorology, climate, solar phenomena, weather phenomena, data collection, measurement. Math: statistics, data analysis.

Table 1

These activities were field tested in Virginia middle schools during the 1991-92 year. These and additional *T/S/M Integration Activities* are currently being field tested nationally. An external evaluator from the Center for Survey Research at Virginia Tech is directing the evaluation component of the project. Formative evaluations are yielding data that is useful in revising the activities and in developing in-service materials for teachers. These materials, designed to orient new teacher teams to the *T/S/M Integration Activities* and approach, were distributed to about 40 national field-test sites in 1992. In addition, data with respect to students' attitudes toward the *T/S/M Integration Activities* is being collected to provide an indication of their assessment of this approach.

Teacher and student feedback from the national field-test sites has been helpful in fine-tuning the Activities. Finally, the materials will be readied for publication and wide scale distribution in early 1994.

Summary

The paradigm shift from industrial arts to technology education has moved our field in new directions. One of the emerging initiatives is greater integration with science and mathematics curricula. While we have historically done relatively little to formally incorporate science and mathematics principles with our hands-on activities, technology based problem solving activities are an ideal "platform" for doing so. It is an opportunity we should not let pass us by.

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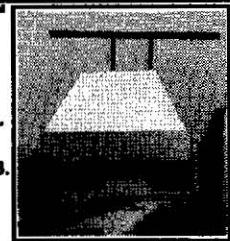
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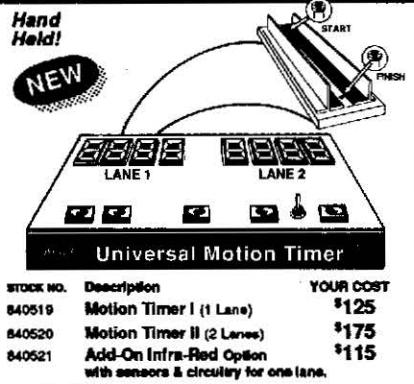
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