The Effects of Technology Education, Science, and Mathematics Integration Upon Eighth Grader's Technological Problem-Solving Ability

by

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Abstract

This study investigated the effects of technology education, science, and mathematics (TSM) curriculum integration on the technological problem-solving ability of eighth grade technology education students. The researcher used a quasi-experimental, nonequivalent control group design to compare the performance of students receiving correlated TSM integration to those not receiving integration in an adapted Technology, Science, Mathematics Integration Project Activity (LaPorte & Sanders, 1993).

The students were to design, construct, and evaluate wind collectors to generate electricity. The collectors were mounted on a generator for the pretest and posttest measurements. The measure for treatment

effect was the output wattage of the generator for each student's wind collector.

The samples were drawn from middle schools that had two technology education teachers in the same school, each teaching eighth graders. The pilot study sample (N = 51) was selected from a middle school in rural south-central Virginia. The study sample (N = 33) was selected from a middle school in a suburb of Richmond, Virginia.

Treatment group technology education teachers employed technological problem solving, and they correlated instruction of key concepts with science and mathematics teachers using the adapted TSM Integration Activity. The control group technology education teachers did not correlate instruction with science and mathematics teachers.

There was no significant difference between the treatment and control groups for technological problem solving. Evidence suggested that students were applying science and mathematics concepts. The researcher concluded that TSM curriculum integration may promote the application of science and mathematics concepts to technological problem solving and does not hinder the technological problem-solving ability of eighth technology education students.

To Susan, My Best Friend,

This volume of research is dedicated to my loving wife, Susan, without whose support I could not have accomplished what I have. All things of the Earthly realm pale in comparison to my love for her; her beauty, intelligence, sensitivity, compassion, dedication and motivation. In partnership with her, our life together and the holy vows of our union are the most sacred and important purposes of life for me on Earth.

The Teacher as Investigator

"It seems to me that the contributions that might come from class-room teachers are a comparatively neglected field; or, to change the metaphor, an almost unworked mine...It is to be hoped that the movement will not cease until all active class-room teachers, of whatever grade, are also drawn in...For these teachers are the ones in direct contact with pupils and hence the ones through whom the results of scientific findings finally reach students. They are the channels through which the consequences of educational theory come into the lives of those at school" (pp. 46-47).

John Dewey, 1929

The Sources of a Science of Education.

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Chapter One

Introduction and Rationale

Nature of the Problem

During the 1970's, academic test scores declined, fostering the "back-to-basics" movement. Minimal competency testing was the Nation's initial response to the problem. The decline in scores was seen to be a lack of attention to standards in education (Wise, 1979, pp. xv, 26).

In the 1980's, the focus shifted from minimal competencies to reform that addressed the needs of schools and students above the minimum. Many of the educational reform reports in that decade were written toward that end (see Adler, 1982; Boyer, 1983; Goodlad, 1984). Many of the reports linked the economic problems of the Nation to poor educational achievement.

Most educational reform reports in the second half of the decade, however, called for higher standards for curricula, academic achievement, and new approaches to teaching and learning (Michaels, 1988, p. 3). Most of the reports call for reform in technology, science, and mathematics education. Almost without exception the basis for the claims and propositions was declining student achievement and the waning economy.

This decline in student achievement was quantified in a study conducted between 1983 and 1986 that compared the science achievement of students in seventeen countries. The United States ranked eighth for ten year-olds, fourteenth for 14 year olds, and thirteenth for biology, chemistry, and physics at the twelfth grade level (International Association for Evaluation of Educational Achievement, IEA, 1988, p. 3). With respect to science education in the United States, the report concluded: "For a technologically advanced country, it would appear that a reexamination of how science is presented and studied is required" (p. 9). These results were similar to those reported by the National Science Board (1987).

A variety of sources called for similar reforms in science and mathematics education (see Project 2061, 1989; Scope, Sequence and Coordination of Secondary School Science Project, SS & C, 1992; Commission on Standards for School Mathematics of the National Council of Teachers of Mathematics, 1989; National Committee for Science Standards and Assessment, 1993; Maley, 1992;

LaPorte & Sanders, in press). With the exception of the SS & C Project, all of these efforts called for the integration of the technology, science, and mathematics curricula, as one of several means to improving student achievement.

Science education reform. In 1989, the American Association for the Advancement of Science sponsored what might be considered the most notable effort at science education reform for the 1980's and 1990's. This reform effort is spearheaded by the Project 2061, and its first phase produced recommendations for technology education, science, and mathematics including the integration of these curricula (Johnson, 1989, p. vii). Part of the phase I task was determining the place of technology in achieving scientific literacy (p. viii). The science education of all students should reflect the widespread influence of technology in modern life and should use hands-on laboratory experiences toward achieving that end (p. xi).

Mathematics education reform. In the same year, the National Council of Teachers of Mathematics' Commission on Standards for School Mathematics published 13 standards on curriculum in addition to standards in other areas of mathematics education. One curriculum standard in particular called for the integration of mathematics with other subjects including industrial technology (p. 86). Industrial technology is the generic name given to the field of education related to technical training and general technological education including technology education.

Technology education reform. In the 1950's, Maley was prominent among those who were pressing for reform in industrial arts, now known as technology education. The central themes of his reform ideas were curriculum integration, research and experimentation, and problem solving. He believed that curriculum integration held three primary benefits for technology education (Maley, 1985, p. 7). The first was truly developing an understanding of technology in the student; this would be impossible without linkages with science and mathematics among other areas. Second, he believed that the hands-on experiential learning approach was the key to holistic learning, that might be described as the product of true curriculum integration. Finally, he believed that the recent emphasis on the importance of science and mathematics in education was an opportunity for technology education to become recognized as an important academic discipline. Maley believed this would be achieved through partnerships including curriculum integration.

A Rationale for This Study

Morse (1958, p. 168) wrote about the needs for further research in curriculum integration. There are several difficulties in conducting research on integration including the validation of criteria and instruments for measurement. The few instruments applied to studies of integration prior to 1958 were not very successful due to the complexities surrounding the school and the curricula. Morse's message is that further research should try to work around and control these limitations and confounding variables.

Mayhew (1958, p. 248) reiterated the need for further research into the effects of curriculum integration.

> ...human beings are apt to lose interest unless they can gain some...evidence of the effects of what they are doing...attempts at integration have considered...the means to the desired end. They

> have not given attention to how to determine whether or not the end has been achieved. A necessary future step...will be to devise ways of appraising the effectiveness of whatever is attempted.

Little has changed since 1958. LaPorte and Sanders (in press) cited research on hands-on science and the effects of various integrated curricula related to technology, science, and mathematics. They concluded primarily that much more research is needed especially in the field of technology education; its hands-on approach and its effects on student attributes in an integrated curriculum arrangement. They concluded that many curriculum integration and hands-on treatment studies were conducted during a period when technological problem solving was not defined with its present meaning. They also believe that previous studies were inconclusive in the identification of the unique contributions technology education makes to student learning, learning in other disciplines, and the effects of hands-on instruction. However, they were certain of one thing, "Research from a range of sources,...suggests further exploration of the notion of content integration is warranted" (p. 29).

Loepp (1992, p. 19) also recognized the lack of studies on curriculum integration and the limitations encountered by researchers.

From the perspective of science and mathematics educators, the question of technology education's contribution to science and mathematics achievement is important. This is also an important question to research if the technology educator is concerned about demonstrating a reason for technology education to share part of the "turf" with "mathematics and science, the owners of the 'playing field'" (Salinger, 1992, p. 43). This is precisely Loepp's (1992, p. 16) stated need for research in curriculum integration.

The antithesis is equally important and needed from the perspective of technology educators. Do technology education students achieve in technology better when their technology education teacher correlates planning and instruction with their science and mathematics teachers? The basis for this research is found in an important recommendation by Waetgen (1992, p. 29). He proposed an agenda by which the field of technology education would establish itself as a discipline in its own right. Technology education curriculum research is included in this agenda, and it encompasses curriculum standards related to identifying measures of student competence and content unique to technology education. Waetgen emphasized that there will be no simple approach to the research and development of such a foundation for technology education curriculum standards. (p. 29)

The most appropriate research based upon the preceding perspectives should focus on technology, science, and mathematics curriculum integration and its effects on technology education students.

Student competence in technology education. The overriding goal of technology education is to develop technological literacy in students. Technological literacy entails an awareness of the technological and related sociological problems and alternatives to them (Technology Education Advisory Council, TEAC, 1988, p. 7). The technologically literate person studying the four elements of a technology education curriculum or program understands:

- the history of technology.
- invention and innovation, and is able to conduct technological processes.

- the systems of technology including production, transportation, communication, and the application of machines, materials, tools and other resources.
- the assessment of technology and its interaction with the human society (TEAC, p. 10).

A major part of technological literacy is technological problem solving (Savage & Sterry, 1990, p. 15). It is a major cognitive strategy employed as human wants and needs are addressed. For technology, technological problem solving serves as a parallel to the scientific method in science (p. 10). Technological problem solving is the major process by which technology is created and is identified as a major technological process. Student competence in technology education, then, could be a measure of technological problem-solving ability.

A final perspective on the rationale for this research. Waetgen (1989, p. 4) identified a need for the research proposed herein. The subsequent chapter will thoroughly examine technological problem-solving, but the manner in which it is implemented and the model of the process are areas of needed research in technology education. Waetgen believes it is possible to develop a defensible strategy or approach to problem solving that is unique to technology education. If such a goal is accomplished all variables related to the process will need to be researched and modified accordingly. "Both aspects are important: development of a paradigm of problem solving and research to test it" (p. 4).

Significance and Purpose of the Study

This study is a direct result of several need statements and proposals published in the field of technology education, and it is a direct testing of key recommendations made by important national organizations representing the fields of technology education, science education, mathematics education, and government. These recommendations called for the integration of technology education, science, and mathematics curricula, and the calls for further research are a result of the lack of research in curriculum integration in the face of those major recommendations.

Much of the cited literature represents a consensus that a major attribute of student achievement in technology education is the student's ability to solve technological problems. Measures of this ability were the quantities used to evaluate the performance of the technological solutions that students built (Lux, 1985; Waetgen, 1989; Savage & Sterry, 1990; Sanders, 1993).

Using curriculum integration materials adapted from the Technology, Science, Mathematics (TSM) Integration Project (LaPorte & Sanders, 1993), treatment subjects were to apply science and mathematics concepts to the solution of the technological problem. This process was indirectly measured by the performance of the technological solutions or the measure of the student's technological problem-solving ability. Additionally, an understanding of this process was also ascertained through the qualitative methods of interviews in technology education class (Glasson, 1993).

Research Question

This study addressed one major research question.

1. What effect does technology, science, and mathematics correlated curriculum integration

have upon the technological problem-solving ability of eighth grade technology education students?

Assumptions

The following assumptions were made about this study and the circumstances surrounding it.

1. The teachers participating in the study followed the procedures and schedule in the adapted TSM Integration materials.
2. The procedures and schedule in the TSM Integration materials adapted for the study were understood by the participating teachers, and they had the skills to carry them out.
3. The treatment teachers and the control group teachers were equal in their ability to teach technological problem solving.
4. The measures of technological problem-solving ability used for both the pretest and posttest were reliable and valid. They measured the extent to which the technological solution met the stated design criteria in the adapted TSM Integration activity. These criteria were a

measure of the degree of the student's problem-solving ability and his or her ability to apply science and mathematics concepts.

Limitations

The study was conducted under the following limitations.

1. The sampling units for this study were intact groups, and these groups were not randomly assigned to treatment or control groups. Instead, the treatment teachers were chosen based upon their schools' interest in TSM curriculum integration and the availability of the science and mathematics teachers.
2. Not all of the treatment group were taught their regular science and mathematics by the participating treatment-group science and mathematics teachers. However, all of the treatment-group subjects were taught the adapted TSM Integration science and mathematics treatment by the participating science and mathematics teachers during a

split period. The split period entailed science and mathematics instruction during the first half of class followed by laboratory time for technological problem solving during the second half of each period.

Delimitations

The delimitations listed below were necessary to control experimental variability, and expenditures in time and money.

1. The study was delimited to eighth grade technology education students.
2. The sample consisted of technology education students at two middle schools located in two Virginia school divisions. One school served in the pilot study and the second served in the revised study.
3. The length of time for the treatment and the experiment was limited to five weeks or 24 hours of instructional time per student (LaPorte & Sanders, 1992, p. 7).
4. In the TSM Integration Activity chosen to be adapted for this study, the success of

technological solutions was more contingent upon the application of key science and mathematics concepts; more so than other TSM Integration Activities. For example, the successful student-made wind collector and generator will be one that maximized its use of volume. One control on the solution is that the wind vane fit inside of a certain volume of space. One of the mathematics concepts is how to maximize volume. The success of the solutions is very contingent upon this concept.

Operational Definitions

The following terms are defined by their intended meaning in this study or by their meanings in the context of cited references.

Control group. Those students whose technology education teacher does not correlate planning and instruction with another teacher (Ary, Jacobs, & Razavieh, 1985, p. 259).

Correlation. An interdisciplinary curriculum integration design in which teams of teachers teach concepts in their own areas that relate to a theme or overlapping concept (Van Til, Vars, & Lounsbury, 1961, p. 90).

Curriculum integration. "The problem of finding those underlying facts and principles which...relate it to other disciplines" (Dressel, 1958, p. 11).

Integration. "The problem of finding those underlying facts and principles which...relate it to other disciplines" (Dressel, 1958, p. 11). Defined twice as others in education use them interchangeably.

Interdisciplinary. "A knowledge view and curriculum approach that consciously applies methodology and language from more than one discipline to examine a central theme, issue, problem, topic, or experience" (Jacobs, 1989a, p. 8).

Problem solving. "A process of seeking feasible solutions to a problem" (Hatch, 1988, p. 89). Educators employ it routinely as an instructional approach or activity (p. 93).

Technological problem solving. The systematic technological method of seeking solutions to technological problems and requires the application of technology (Waetgen, 1989, p. 4; Barnes, 1989, p. 26). It "is predicated on the application of ideas and understandings to create very practical solutions" (LaPorte & Sanders, 1993, p. 19).

Technology. "A body of knowledge and the systematic application of resources to produce outcomes in response to human needs and wants" (Savage & Sterry, 1990, p. 7).

Technology education. "The school discipline for the study of the application of knowledge,...and resources to solve problems and extend human potential" (Technology Education Service, 1988, p. 8). It "is the study of technology and its effect on individuals, society, and civilization" (Savage & Sterry, 1990, p. 20).

Technology, Science, Mathematics Integration Activity. An activity developed by the TSM Integration Project. The activity is designed "with mathematics and science application as the primary objective" (LaPorte & Sanders, 1993, p. 19). The activity is designed to integrate technology education, science, and mathematics curricula in the middle school (p. 17) through a correlation approach (LaPorte, & Sanders, 1992, p. 2).

Treatment group. Those students whose technology education teacher correlates planning and instruction with the participating science and mathematics teachers (Ary, Jacobs, & Razavieh, 1985, p. 259).

Summary

The latter half of the 1980's in education was characterized by reform reports that called for revised standards and new approaches in technology, science, and mathematics instruction as a means of raising achievement and preparing a literate workforce. With science scores falling government commissions and national educational organizations theorized that, among other efforts, curriculum integration was one approach worth trying to improve student performance. Maley (1967), the Project 2061 (1989), and the Commission on Standards for School Mathematics (1989) are examples of such reformers.

The effects of curriculum integration are difficult to measure, and relatively little research has been conducted on the subject. The point was made that regular practice in educational methodology should be founded upon research. For technology education, science, and mathematics integration, there are several perspectives to the research. It would be useful to scientists, mathematicians, and those who promote technology education as an academic discipline, equal in importance to more established fields, to measure the effects technology education has upon the science and mathematics achievement of students. However, there is much founding work to be conducted in field of technology education that mainly contributes to establishing technology as a discipline and technology education as its interpreter in the public schools especially (Waetgen, 1992, p. 29). This work includes curriculum research and the investigation of curriculum integration and its effects on student achievement in technology education that primarily includes understanding the processes of technology through experience (Savage & Sterry, 1990, p.15) and technological problem solving (TEAC, 1988, p.10).

The research described herein measured the effects of correlated planning and instruction in technology education, science, and mathematics on the technological problem-solving ability of technology education students. This treatment effect was compared to the technological problem-solving ability of technology education students whose teacher did not correlate instruction with other teachers.

Chapter Two

Review of Related Literature

Introduction

Curriculum integration came to be "seen as the next generation of teaching methodology in the secondary" school through a gradual process (Bailey, 1991, p. 36). According to Michaels (1988, p. 3) the past decade in education was characterized by two waves of educational reform and a large number of educational reform reports. Many of these reports linked the economic needs of the United States to recommendations for improving the nation's public schools and curriculum (see National Science Foundation & U. S. Department of Education, 1980). The first wave of reform focused primarily on schools raising the amount of academic instruction or "do more of what the schools were already doing" (Micheals, p. 3).

The second wave emphasized developing national standards and trying new approaches to instruction. Some of the more influential reports make recommendations that help provide a rationale for integrating the technology education curriculum with science and mathematics. The National Commission on Excellence in Education (1983, p. 25), who set the stage for sweeping reform in education, made recommendations that call for mathematics and science courses that use applications as a method of instruction. Technology education, formerly industrial arts education, has traditionally used a hands-on, application-oriented, problem-solving approach as a primary instructional method (Waetgen, 1989, p. 8; Ritz, 1992, p. 22; Savage & Sterry, 1990, p. 22; Olson, 1974, p. 35; Snyder & Hales, 1980, p. 42). Therefore, technology education is an able partner in a curriculum that capitalizes on applications of science and mathematics recommended by the Commission. "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" (Maley, 1985, p. 7).

Curriculum Reform and Rationale for Curriculum Integration from the Science, Mathematics, and Technology Education Communities

Many of the reform reports that contribute to a rationale for the integration of technology, science, and mathematics originated from governmental commissions, cognitive psychologists, educational philosophers, and private foundations that are concerned with education in a general sense. Many of these reports are necessary in developing a complete rationale. However, the most important contributions to a rationale come from the science, mathematics, and technology education communities. In addition to considering their common recommendations for reform and curriculum integration, it is necessary to demonstrate that, at a pragmatic level, the three curricula are "spiral" in structure and thereby are capable of being integrated in the setting of the school.

Importance of spiral curriculum. Reformers from technology education, science, and mathematics recommend that students learn primarily through problem solving and activity. They also recommend that the content students learn be important to the learner and society (Lauda, 1983, pp. 10-12; Johnson, 1989, p. 5; Blackwell & Henkin, 1989, p. 31). When students move from problem to problem some skills and concepts that are important for solving one problem may not be required for the next. Traditionally, mathematics was a highly sequenced, subject-centered curriculum (Taba, 1962, pp. 177-181). Third graders learned about multiplication. In the fourth grade, students learned about fractions. Tenth graders learned about geometry, and juniors or seniors learned analysis and statistics. In solving a technological problem, an eighth grader may need to learn a simple concept from geometry. In a traditionally-sequenced mathematics curriculum, one that is strictly subject oriented, the student would not study geometry until the tenth grade.

In contrast to the constraints of the sequential subject-centered curriculum, the spiral curriculum design allows teachers to introduce concepts that are important to the goals of the learner as they are needed. In the spiral curriculum, the student revisits important concepts any number of times during his or her schooling. Taba (p. 178) promoted the learning of a concept in a variety of contexts and in a succession of activities. "[Concepts] cannot be isolated into specific units but must be woven into the whole fabric of the curriculum and examined over and over again in an ascending spiral."

Bruner (1977, p. 33) certainly lends credence to the importance of spiral curricula. He hypothesized that any subject can be taught in some intellectually honest form to any child at any level. Based on this hypothesis, Bruner argued that the great ideas that society holds important must be taught early in the education of the child (p. 52). He stated of his hypothesis, "No evidence exists to contradict it; considerable evidence is being amassed that supports it" (p. 33). Consequently, the spiral curriculum has been recognized as the preferred design over the traditional compartmentalized curriculum (pp. 34, 54).

The science community. Among the science education reformers, the primary rationale for the integration of technology, science, and mathematics came from three major science curriculum reform efforts. The SS & C Project (1992) did not recommend integration with technology education specifically, but they did recommend many changes that integration with technology education could assist in implementing. The National Committee on Science Standards and Assessment (1992, p. 5) wrote standards that directly call for technology education, science, and mathematics integration. Finally, the Project 2061 (1989) has published the most extensive recommendations for science reform and directly recommended integration of the three curricula (Johnson, 1989, p. 3).

The Project 2061 (1989), principally concerned with science education, recently reviewed the state of education in the United States and recommended changes and implementation strategies for science, mathematics, technology, and other areas of education. Three years ago the Project 2061 committees completed phase one of the process and identified several important problems.

They include the antiquated methods of science instruction and lack of student motivation manifested by such methods. They revealed that science and technology instruction is all too often descriptive and provides little opportunity for students to apply mathematics to the analysis of science and technology. "Ideally, the interaction of mathematics, science and technology will emerge in the future curriculum from hands-on experience generated by students' interests under the guidance of expert teachers" (Blackwell & Henkin, p. 31).

Because of the epistemic links among technology, science, and mathematics, the Project 2061 (1989) recommended the three curricula be integrated as much as possible. They especially believed that the instructional methods and hands-on approach to technology education instruction makes it a key partner in interdisciplinary arrangements (Johnson, 1989, pp. 3, 5; Project 2061, 1993, p. 29).

The Project also recommended that the processes involved in the scientific method of inquiry and the problem-solving method be used as principal means of instruction. Understanding technology, science, or mathematics necessarily means understanding all three. "The sciences and mathematics are important to the understanding of the processes and meaning of technology. Their integration with the technology education curriculum is vital" (Johnson, 1989, p. 3).

The Project emphasized that scientific literacy would only be achieved if the curriculum structure were changed to usurp the rigid subject-matter boundaries that currently exist. More attention must be paid to the connections among technology, science, and mathematics, and the processes as human endeavors (Project 2061, p. 5; Hamm, 1992, p. 8).

The Project envisioned integrated activities in areas like biotechnology, logic operations, communication, manufacturing, and energy to name but a few. Mathematical processes should be used early as means to understanding other subject matter. Student ideas in using mathematics should grow out of project work in technology and experimentation in science (Johnson, pp. 5-7). "For example,...Students can learn about the advent and importance of telegraphy in the traditional lecture/text way, and at the same time they can design and build a simple telegraph system in the laboratory..." (Johnson, p. 5).

An account of Phase II of the Project 2061 is important to this proposed study because it demonstrates that the science curriculum is a spiral curriculum throughout a student's education. Phase II of the Project 2061 involved teams of experts and educators developing models for the implementation of recommendations. This included the science curriculum.

In developing the science curriculum model, a process called backmapping was employed to "determine the progression of understanding by which students might eventually arrive at the learning outcomes in *Science for All Americans*...What components of each outcome should somewhat younger students already have in order to understand new material" (Project 2061, 1992, p. 14)?

The backmaps reveal a spiral curriculum for science education, kindergarten through the twelfth grade. Physics would not only be taught to seniors, but elementary students would learn physics concepts in a form appropriate to their skills and knowledge. "As a critical mass of these backmaps were produced, ideas emerged for activities and learning experiences that could serve multiple understandings at each grade level" (p. 15). In the context of curriculum integration, the science curriculum model proposed by the Project would provide the opportunity for an eighth grader to learn physics principles that might be necessary to solve a problem in the technology education laboratory.

The culmination of the Project's phase one recommendations and phase two backmaps and curriculum model is a set of curriculum standards entitled *Benchmarks for Science Literacy* (Project 2061, 1993) (published by the American Association for the Advancement of Science, the Project's sponsor). Referred to as benchmarks, these standards have profound implications for the integration of technology, science, and mathematics. Among others in the technical/technological education community, technology education is specifically cited as an important partner in the benchmarks related to the study and integration of technology in the science curriculum (Project 2061, 1993b, p. 29).

Among other benchmarks related to science and mathematics are those related directly to technology and the interrelationship of science and technology. There are twelve groupings of the benchmarks, each grouping related to all grade levels. These groups are referred to as clusters (p. iv). For example, the third cluster, "The Nature of Technology," provides for middle school students the study of technology as the earliest human adaptive system, its synergy with science in the past century, and the role of engineering as a primary field for the application of science in technology (p. 32).

For the middle school, the benchmark cluster referred to as "The Designed World" addresses the history of agricultural technology, the agricultural revolution, and the impacts of communication and transportation on agriculture (p. 139). The "Common Themes" benchmarks include the study of electrical and mechanical systems and the understanding of basic closed-loop systems models (p. 224).

Phase III of Project 2061 (1989) will involve collaboration among major organizations in education. This reinforces the idea that this study was a serious attempt at addressing the concerns of the reform bodies involved. Their goal will be implementing the recommendations and benchmarks of the first two phases of the project. The primary association for technology educators, the International Technology Education Association, was invited to participate in this effort (p. 164).

The SS & C Project is a project of the National Science Teachers Association that designed a science curriculum structure for secondary education. This project was independent of but parallel to the Project 2061. While the SS & C Project did not specifically recommend curriculum integration with the technology education curriculum, they are noteworthy because they did recommend and design the structure of a spiral science curriculum, and recommended that schools eliminate the traditional layer cake science curriculum. The resulting curriculum structure integrates the science disciplines together (p. 14).

The SS & C Project concurred with Bruner's hypothesis, that any subject can be taught to any student in some intellectually honest form, and used it as a rationale for their spiral curriculum structure. As an example of this spiral curriculum structure, the SS & C Project specifies a sequence of earth science instruction for grades six through twelve. In the sixth through the eighth grades, science students investigate minerals and rocks in general, but in the ninth and tenth grades they study igneous and metamorphic rocks specifically (p. 75). During the same years of instruction, sixth through eighth graders study color change and temperature as properties of matter in a chemistry sequence, and the ninth and tenth graders study chemical composition under the same topic sequence, properties of matter (p. 50).

The scope of this study is justified further by recommendations made by the National Committee for

Science Education Standards and Assessment (1992), charged by the National Research Council with developing standards for science education. They believe that there are compelling reasons to teach science and technology both as school subjects and in interdisciplinary units. Students are motivated by the applications of science that technology offers, and the interdependency of science and technology implies an integrated approach. The respective subject areas in the schools are charged to be individually responsible for teaching the content and processes of their disciplines, but all of them are charged by the Committee with the task of teaching interdisciplinary units (p. 5).

The National Committee for Science Standards and Assessment (1993) will likely develop standards related to the integration of science and technology under the heading of "Scientific Connections," that will include "connections of science with technology/engineering." The content will focus on the "practice of science" including its applications in technology (p. 6). The second heading of standards that includes technology will likely be "Science and Human Affairs." It includes the study of the place of science and technology, among other disciplines, in history and society (p. 7). Efforts of this nature assure that there is a realistic opportunity to proceed with studies like the one reported herein.

Other science education reformers. The National Science Board Commission on Precollege Education in Mathematics, Science and Technology (1983, p. v), supported by the National Science Foundation, cited two urgent problems related to technology, science, and mathematics education. First, the nation is not recruiting enough scientists, engineers, and mathematicians. Second, the general population is neither scientifically nor technologically literate enough to effectively cope with the ever increasing complexity of our technological and economic society.

To correct these problems, the Commission recommended daily science and technology experiences at every level, kindergarten through eleventh grade. They maintained that the K through eleven technology, science, mathematics curricula should be integrated with each other in such a manner that the introduction of topics and concepts are not only planned but coordinated among teachers. The curriculum should include applications of technology and science that will help the school community. Technological systems should be a pivot point for organizing the curriculum. And, the curriculum should be organized around problem solving, issues, and decision making (pp. 101-102).

Selby (1988, pp. 4-5), Professor of Science Education at New York University and Co-Chair of the National Science Board Commission, was particularly interested in technology education because "...of all that this area of study can do to help us meet our new goals for mathematics and science education..." (p. 4). She believes that technology is intertwined through the culture. Because students perceive technology with all their senses its study is relevant to them (p. 5).

Hurd (1991, p. 35) characterized the emerging role of science education in curriculum integration. He stated that science education reform in the past had failed because it never considered the scientific literacy of all students but instead fell into a trap of requiring more rigor in the old curriculum. "The reform movement of the 1990's calls for an integration of school subjects: a conceptual convergence of the natural sciences, mathematics, and technology..." (p. 35). This suggests that this study was appropriate given past failures at reform.

An important example of a science curriculum project that reflects the concern of science education for all students is the Active Physics Project (1993, pp. 1-2). The curriculum materials, now under development, promise to take a constructivist approach to thematic units that integrate physics, technology, and mathematics. The activity-based, spiral physics curriculum is designed for students who do not typically enroll in physics classes in high school. The curriculum uses authentic assessment; meaning students demonstrate the applications of the physics knowledge they learned similar to research and development scientists and engineers.

Finally, an important driver of new research in technology education, Gerhard Salinger (1992, pp. 43-44), of the National Science Foundation, urged technology educators to get involved with the science and mathematics communities. He said in a speech to the International Technology Education Association's Pupil's Attitudes Toward Technology Conference that there are great opportunities for technology educators to integrate with science and mathematics because of their belief that activity, problem solving and design should be principal methods of effective instruction. He believes that technology educators have a key role to play in providing such methods, and if they act quickly and decisively technology education could be seen as an equal in TSM integration.

The mathematics community. In March of 1989, the Working Groups of the Commission on Standards for School Mathematics of the National Council of Teachers of Mathematics published standards for mathematics curricula and evaluation that dramatically depart from the traditional subject-oriented compartmentalized curriculum currently used by many school systems. The existence of these standards provides important support for the implementation of this study. The Commission recommended thirteen basic mathematics standards for kindergarten through the twelfth grade.

A major recommendation of the Commission in standard four, "Mathematical Connections," is that mathematics be integrated with other school subjects. The recommendation is a key area in which technology education contributes. Integration is seen as a way for students to observe the usefulness of mathematics in describing the real world, apply mathematics to solving real-life problems, and apply mathematics in different contexts (pp. 84-86).

The Commission's recommendations emphasize the importance of developing problem-solving skills and creating opportunities for students to solve problems set in real-life contexts; problems similar to those used by technology educators, that are not always easy to solve and might have too much information or not enough information available. They envisioned active learning and student manipulation of physical objects. Standard one is entitled "Mathematics as Problem Solving." "The curriculum must give students opportunities to solve problems that require them to work cooperatively, to use technology,...and to experience the power and usefulness of mathematics...Real-world problems are not ready-made exercises with easily processed procedures and numbers" (pp. 75-76). The Commission emphasized the "doing" of mathematics as more important than the knowing of mathematical facts (p. 7).

Roth (1993, a writer and researcher in mathematics and cognition, presented an interesting perspective when developing a rationale for the integration of mathematics and science; useful here because it reflects the methods used in technology education. He maintained that most instruction in the present educational system is based upon an objectivist or positivist epistemology. "...teaching and learning are described by a conduit metaphor according to which knowledge may be transferred from the mind of the teacher to that of the student...similar to information...transmitted from...sender to...receiver" (p. 113).

He explained that the alternative epistemology, constructivism, is probably a more realistic perspective for understanding the learning process. In cognitive constructivism, knowledge is constructed in the person's mind through experience, and this experience makes one person's understanding of a concept different than another person's understanding. People assimilate what is experienced with previously held understandings. If the experience differs from a learner's expectation then conceptual understandings are changed in the learner (von Glasersfeld, 1987, pp. 129-132).

Roth proposed that the recognition of cognitive constructivism as a basis for pedagogical theory provides a need for the integration of science and mathematics. "...the current problems of schooling are related to the distance between practices at school and those of everyday life...the curriculum should integrate real-world problems with school subject matter and...support student's efforts in constructing meaningful knowledge" (p. 113).

The technology education community. The first widely recognized relationship among industrial arts education, science, and mathematics was the perceived need to integrate science and mathematics content into the industrial arts curriculum after the introduction of a new curriculum in 1947. Since that time, reformers in industrial arts and technology education have made significant contributions to a rationale for the integration of technology, science, and mathematics.

Although industrial arts was perceived to be general education, the Selvidge Plan began to gain support for its vocational approach (trade analysis) to industrial arts from the late 1920's through World War II (Martin & Luetkemeyer, 1979, pp. 32-33, 36). Although the field was in the process of being vocationalized

(Barella, 1981, pp. 150, 158), literature appears in the mid 1940's that recognized the multidisciplinary nature of industrial arts (Mones, 1944, p. 4; Jellison, 1945, p. 1). An early industrial arts reformer, William Warner, proposed a general approach to the study of industry that integrated industrial technologies. He proposed a curriculum that focused on areas of industry such as manufacturing and communication. This contrasted the traditional and popular approach used in the unit shop. The unit shop approach required students of woodworking to study in the woodworking shop; metalworking was studied in the metalworking shop (Starkweather, 1979, p. 78).

Delmar Olson took Warner's ideas further and proposed that the content of industrial arts should be derived from analyses of technology (Martin & Luetkemeyer, 1979, p. 37). As the Warner proposal (the New Industrial Arts Curriculum) and the Olson proposal gained acceptance, it became apparent that the general approach to the study of industry and technology would require a general laboratory and knowledge of mathematics and science (p. 36).

Newkirk (1947, p. 1) made one of the earliest references to the integration of the industrial arts curriculum with others by coordinating instruction with teachers from other disciplines. He characterized such an approach as appropriate to the scope of the industrial arts curriculum in the intermediate school.

Donald Maley (1959, p. 12) was the principal advocate of integrating mathematics and science into industrial arts. The primary reason Maley saw a real need for content integration was to prepare students in a curriculum he was designing that emphasized research and experimentation. (Maurice Richards, 1958, p. 214, made an earlier reference to the need for experimentation and integration with mathematics and science.)

Maley's argument was that modern industry was built on science and mathematics. He not only recognized that the industrial arts curriculum should reflect this relationship, but he also recognized that industrial arts educators were in a key position to improve general education through teaching the applications of science and mathematics. "...Where else in the school is there the possibility for the integration and application of the mathematical, scientific, creative and manipulative abilities of youngsters..."(1959, p. 12)?

Maley (p. 16) also urged the industrial arts teachers of the day to coordinate their efforts at integration, application and research and experimentation with the rest of the school program. This idea of coordination would grow as Maley developed his curriculum known later as the Maryland Plan, a major curriculum effort demonstrating the importance and magnitude of his influence in this rationale. The notion of curriculum integration as a necessity for industrial arts in the study of technology became only a stepping stone to his later desire to reform general education through curriculum integration. In the field of industrial arts, it was primarily Maley who recognized that the separation of subjects in the schools was a poor educational practice. He proposed curriculum integration as a remedy for the failing subject-centered schools. "...the modern school is highly ineffective in many areas simply because of the compartmentation [sic.] of the total program...The realistic application of the elements of mathematics, [and] science...are inherent in the Industrial Arts objectives and functions" (Maley, p. 12).

In the tradition of the more popular industrial arts approach, the unit shop, R. L. Woodward (1960; 1962) developed units of industrial arts that focused on the applications of science and mathematics in the industrial arts laboratory.

In a special issue of the *Industrial Arts Teacher* on the role of industrial arts as the interpreter of technology, Maley (1972, p. 62) wrote about the need for industrial arts content to be relevant to the interests and concerns of the students. He proposed that content draw from the social problems of the day and of the future. The technology program would become an "interpreter" or means for students to develop solutions based partly on applications of technology but that would also inherently require the involvement of most other subject areas in the school.

He envisioned a good deal of design, construction, and evaluation of solutions to these social problems going on in the industrial arts laboratory. Such a curriculum approach would provide students with the chance to apply what they learned in other school subjects, and require the help and involvement of teachers in other subject areas (p. 62).

Maley (1992, p. 10) identified ten guidelines for the effective use of problem solving as a method of instruction in technology education. One of the guidelines specifies interdisciplinary instruction and demonstrates a relationship between the treatment for this study and the problem-solving approach the teachers are to use. Maley reasoned that all problems are multidisciplinary in nature. Therefore, most technological solutions to them would be incomplete without integration. Also, integration is necessary to provide relevance to the student's general education.

Olson (1973, p. 7) explained the primary purposes of industrial arts. One purpose is to provide a laboratory for the discovery, application, and testing of theory in the academic fields. He stated industrial arts provides the means and setting for the application of mathematics and science, among other academic subjects. He explained that such interdisciplinary arrangements reinforce the academic efforts to teach thinking and problem-solving skill through real experiences.

Reinforcing academic concepts was but one role of industrial arts in the context of general education.

Olson (1972, p. 35) wrote extensively about the role of industrial arts as the interpreter of technology; its number one purpose (1973, p. 8). He suggested that industrial arts would not simply provide laboratory space in which other subject areas could experiment. Rather it strengthened an interdisciplinary study by virtue of its uniqueness. He suggested that industrial arts would be a genuine participant in interdisciplinary studies of the sociocultural aspects of technology (1972, p. 35).

As previously mentioned, Olson (1963, p. 165) advanced the new industrial arts curriculum of Warner into a study of technology. In doing so, he also proposed general functions of industrial arts. His work could be characterized as the foundation that fashioned industrial arts content into that which is related to science and mathematics per se. He added areas of technology study to the new curriculum that were interdisciplinary in nature. Industrial research, the work of the chemist, and the role of mathematics in scientific research are but a few of these areas (pp. 227- 228).

The structure of the present technology education curriculum reflects the pioneer work of Warner and Olson, however it is a spiral structure. For example, students in the elementary school might study transportation as it relates to their families, school, or neighborhoods. In the middle school, the curriculum might focus on different forms of transportation in society, and at the high school the curriculum provides the opportunity for students to study transportation technology and problems in depth. The program of instruction is activity oriented and involves inquiry and problem solving as major instructional methods (Lauda, 1983, pp. 10-12).

Lux (1984, p. 20) recognized the relationship between technology education and science education. He recognized the need to modernize education by means of coordinated, relevant science and technology instruction, and he acknowledged the benefits for students in an organized arrangement with science instruction. Technology teachers are typically weak in science and science teachers are weak in technology. Interaction between the two would only strengthen student learning.

Finally, LaPorte and Sanders (in press) provided a rationale for curriculum integration in their description of the preparation of teachers interested in the integration of technology and other fields and disciplines. The study of technology in relation to other fields or disciplines is incomplete without learning "real" technology. Learning technology is principally accomplished by "doing" technology. Technology education contributes to integrated curricula by strengthening the traditional weaknesses of science and mathematics (among other academic fields); their failure to teach application.

Other Reformers and the Integration of Technology Education, Science, and Mathematics

Many other educational reformers provide rationale and broad support for the integration of curricula and this study. Some provide specific arguments for technology, science, and mathematics integration, and others provide rationale for integrating curricula in general. Nevertheless, their leadership and knowledge in the effort are considerable.

Science-Technology-Society (STS). Roy (1990, p. 13) characterized the STS approach to learning as a social problems focus that incorporates hands-on learning. Gilliom, Helgeson, and Zuga (1991, pp. 232-233) described STS as an emerging multidisciplinary field of scholarship that is finding its way into the public schools and higher education. This educational "infant" provides the opportunity for the integration of science and technology in a sociological context. Its chief rationale is a recent recognition that students fail to understand the relationships among science, technology and the modern society (Kranzberg, 1991, p. 235). Such an understanding is considered vital. A fundamental contribution of technology education to STS is its tradition of laboratory practice. "The activities conducted in technology education labs have been created to illustrate the relationships of means to ends, of the content to practice and of our use of technology to solve social problems" (Zuga, 1991, p. 264). In practice, the STS approach provides a strong emphasis on social science as opposed to technology, and few technology educators have participated in developing STS curricula or implementation (Sanders, 1993, p. 56).

Yet, laboratory activities in technology education are more than illustrative. At the core of laboratory activities in technology education, "doing" technology guided by a theory of practice is the principal means of instruction. While the study of science and modern society is necessary for a complete understanding of technology, the "doing" of technology is equally necessary (LaPorte & Sanders, in press).

The Carnegie Foundation. Boyer and the Carnegie Foundation studied the Nation's high schools and wrote recommendations about the curriculum. They recommended that all students take at least one semester of technology some time during their secondary school experience. They observed that schools have dwelled on computers, but they believe technological literacy should focus on technology in general (1983, p. 111).

Boyer cited an essay by Bernstein (1982, p. 9) in which the physics professor from Stevens Institute of Technology writes about the reasons non-scientists should become involved in science and technology. Of all the problems in our society related to science and technology, Bernstein believed that most will be solved by the non-scientist. He identified three types of science students: those who are curious; those who are bewildered by science and technology; and those who need to understand science and technology by necessity. The implications are that the methods of technology education when integrated with science and mathematics could assist in educating science students who traditional approaches have failed to reach in the past.

Boyer believes that students should be encouraged to identify and understand the linkages among the various subjects they learn. "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..." (p. 114). Teachers should coordinate their efforts to provide an interdisciplinary perspective from which students may more clearly understand the nature of knowledge and the interaction of society (pp. 114-115).

Dewey (1917, p. 157) also argued that the isolated nature of the disciplines undermines the potential in a student in so far as a particular subject may not have interest to a student. Were the concepts presented in a context familiar to the learner, the act of learning would be realistic, purposeful, and more effective.

The Woods Hole Conference. Research indicates that students lack motivation to pursue science and mathematics instruction beyond that required (Raizen, 1982, pp. 4-5). Bruner (1977, p. 31) identified how properly organized knowledge plays a key role in the motivation of students to understand and pursue further learning. He led experts in a study of public education, and they examined the nature of learning, knowledge, and instruction. From this examination, Bruner identified a number of fundamentals of instruction that would motivate the learner.

One way to create motivation to learn is by providing an understanding of the principles in a subject, instead of focusing solely on specific skills and facts, thereby making what is learned transferrable to other problems. In curriculum integration, attention to the connections among disciplines and their methods of inquiry fulfill the fundamentals of structure and motivation (Jacobs & Borland, 1986, p. 161). The transfer of what is learned into the context of other disciplines could be facilitated by the technology education laboratory where the principles of science and mathematics can be applied to assignments reflecting real-life situations.

The middle school community. Just prior to the start of the middle school movement (Dyer, 1993, p. 37), Van Til, Vars, and Lounsbury (1961, pp. 90-97) presented reasons to correlate instruction among the subjects in the junior high school. Their influence is important in a rationale for the integration of technology education, science, and mathematics. Correlating subjects allows students to understand knowledge from a holistic perspective. The process provides more opportunity for critical thinking and problem solving. Curriculum integration provides the opportunity for students to study issues that relate to their concerns as adolescents. And, it eliminates overlap and repetition in the curriculum.

Vars (1986, p. 3) in the midst of the middle school movement, criticized the structure of the junior high school and the "transitioning" middle school. Primarily, traditional middle or junior high schools are set up to be miniature high schools with the departmentalized structure of subject areas. Yet, integrated curricula are essential to the needs of the adolescent and the middle school.

Beane (1991, p. 9) characterized true integration as activity and experience oriented. In recognition of the way students integrated knowledge "into their own systems of meaning" (p. 9), such a process begins with a constructivist's point of view. The integrative process at the middle school level, in Beane's view, should be child centered, relating to his or her concerns and questions about self and society (Beane, p. 12; Tyler, 1949, p. 12). Technology education should be a key partner in bringing activity and experience-oriented instruction to the student.

Jacobs (1991a, p. 24) cited three primary reasons to integrate curricula at the middle school level. From a practical standpoint, there is no room in the curriculum for the swell of new knowledge fighting for a place in the schools. The focus of integration should not be on more knowledge, but the middle school should teach fewer facts and provide better instruction fostering general understanding, learning skills, and affective skills. Integration is necessary to provide relevance in the minds of students. Finally, integration provides sensible curriculum organization and instructional scheduling; deliberately connecting disciplines and scheduling instruction with the content of one subject taught in relation to the content of others.

Approaches to Curriculum Integration

This study employed a TSM Integration Activity for use with the treatment team of teachers and the control technology education teachers. There is a consensus in the literature on how to approach integrated instruction and what the supporting instructional materials should include. The following support the treatment approach and the TSM Integration materials used for the study.

Tyler (1958, pp. 112-113) outlined the most basic organizational elements of integrated curricula, and explained their two primary functions in the context of formal education. Integrated curricula should be organized around concepts, skills, or values. An integrated curriculum should provide horizontal integration of learning and assist in the student's integration of knowledge throughout his or her schooling; vertical integration. Any specific concept, skill or value is worth teaching if it helps accomplish these two integrating functions. For example, transportation of people is a concept that meets Tyler's criteria. In the elementary school, children study and understand that families drive cars or many city people take the bus or train for important reasons. At the same time, transportation is studied by elementary students in history. Therefore, it provides a component for a curriculum design that functions to integrate knowledge horizontally. The middle school student also studies transportation with more breadth and depth, thereby accomplishing vertical integration. Tyler's criteria appear to form the foundation of most integrated curriculum designs. TSM Integration materials provide horizontal integration within a specific middle grade, and they can be used to vertically integrate concepts of technology throughout the middle school years.

Integrated curriculum design. Taba (1962, pp. 302-303) set criteria for the logical organization of an integrated study. Primarily, the organization depends upon the learning objectives. She provided an example. Suppose understanding life in South America is the learning objective. Logically, there are two approaches to the design. First, a single country could form the central focus of the unit, and all aspects of life in that country could be studied. Alternately, a principal aspect of life, say government, could be the focus and studied in relation to many different South American countries. In order to choose which design is best, the curriculum writer must ask the following questions.

- What is harder to learn when not couched in curriculum integration; the relationship of one country to many life aspects common to South American countries or the relationship of one aspect of life in all South American countries?
- Which of these relationships is more important to learn and should be supported by an integrated design?
- Which relationship will provide the greatest depth of understanding?
- Which relationship will provide the greatest breadth of understanding (p. 303).

Van Til, Vars, and Lounsbury (1961, pp. 90-96) outlined three basic types of interdisciplinary curricula designs. Correlation is the most common type of integrated curriculum at the secondary level. Teams of teachers teach concepts in their own areas that relate to a theme or overlapping concept. This is the design that TSM Integration materials support. The second type of curriculum, fusion, combines the content of two subject areas into one course. For example, the technology teacher may teach a course or unit on the technology of the 1700's and its effects on colonization. The third basic type of integration curriculum is the core. The core uses the content of many areas so long as it relates to the problem at hand.

In fairness to the issue, there are critics of the correlation design. Beane (1990, pp. 15-23), in a critique of the middle school, pointed out that schools and teachers should move beyond correlation of subjects to a "true" integration of the curriculum. His idea of the integrated middle school is the core. Every aspect of middle school organization and curricula should focus on the needs of early adolescents. The horizontal function of this integrated core brings together the concerns of society and the concerns of adolescents. From the intersection of these concerns, emerge themes of integrated units such as wellness, justice, and caring.

There are basic approaches to interdisciplinary teaching or staff organization. The total staff approach includes almost all teachers in a school teaching around a single theme. However, not all subjects will readily relate to a given theme, and the weakness with this arrangement is that it may produce only token instruction (Vars, 1987, p. 5; Palmer, 1991, p. 57).

The interdisciplinary team is a second approach. This is the type of integration most frequently used in the middle school. No in-class team teaching is required, and common planning is frequently provided in the master schedule. These team members have a great advantage because they teach the same students. One drawback is that elective-course teachers are often left out of teams and do not have planning time in common with any team in the school (Merenbloom, 1986, pp. 6-7). TSM Integration materials are designed to support the interdisciplinary team.

The third approach is the block-time or self-contained class, that is most common in the elementary school. The self-contained teacher is responsible for teaching all of the required subjects to students; these subjects could be integrated. The block-time teacher provides instruction in two or more subjects. The disadvantage is that at the secondary level, content becomes almost too sophisticated for one person to teach effectively (Vars, 1987, p. 9).

Jacobs (1989b, pp. 15-18) described design options for integrated curricula that are all variations of those basic integrated curriculum designs described by Van Til, Vars, and Lounsbury. "Parallel Disciplines" is a design option wherein the teachers of different subjects schedule lessons on similar or related content at the same times throughout the year. "Complementary Disciplines" is an option that combines related subjects into a formal course or unit of study. "Interdisciplinary Unit" periodically brings all of the school's subjects together in a short-term unit of study. "Integrated-Day" brings together all teachers and students in the study of a theme or problem for a day. "Complete Program" is total true integration where students study issues, problems, and knowledge from real life. The school has no subject-area structure.

Jacobs (1991b, pp. xiv-xv) went on to develop ten models of integrated curricula that can be classified into: (1) integration within a single discipline; (2) integration among a few disciplines; and, (3) integration "within and across" the learner.

George, Stevenson, Thomason, and Beane (1992, pp. 96-97) identified ten characteristics of the effective middle school curriculum. They could provide criteria for future development of integrated curricula and a yardstick by which adapted TSM Integration materials can be measured. The following are the most relevant to this review.

1. The curriculum should be explicitly derived from the concerns of adolescents.
2. The curriculum should be totally integrated and go beyond correlation of subjects.
3. Students should primarily apply knowledge as a means to introspection.
4. Knowledge should be learned and applied in a meaningful context; and,
9. The curriculum should allow students to construct their own understandings.

Zuga (1988, pp. 60-61) described a variety of approaches to integrating technology education with other disciplines. In elementary school, the most appropriate purpose of technology is reinforcing the core curriculum. In high school, an entire course may be designed using technology as the organizing component. Conversely, a course may be designed in which technology serves simply to reinforce a principal discipline much in the way "Principles of Technology" is primarily a course in the discipline of physics. A course may be designed to reflect the synergy of real life. She used "The Orchestrated Systems" program as an example of a course that more evenly emphasizes several disciplines. At the middle school, technology courses are often combined into block-time courses or correlated with other separate subjects.

Zuga implied that technology education should not simply serve as a teaching method for other disciplines. For example, the history teacher wants the technology teacher to participate in a unit on the Jamestown colony because the technology teacher knows how to build a model of the settlement. However, one criterion of what to teach in an interdisciplinary arrangement is that the related content provides a means to understanding technological subject matter (pp. 65-66). This criterion echoes an important factor Lux (1958) emphasized. "There is a need for...integration of...the natural and social sciences. In the process, however, industrial arts [technology education] content must remain the central, dominant theme" [in the industrial arts laboratory] (p. 146).

Jacobs (1991a, p. 27-28) described three phases for the implementation of integrated curricula. In the first phase, teachers collect data on what and when different concepts, skills, etc. are taught in different classes. Related subjects are matched, and opportunities for integration are identified.

Levy (1980, pp. 26-27) suggested that an effective approach to starting the planning process is a strategy called webbing. Used extensively in the elementary school, the webbing process begins with the identification of a primary concept. From that point, the teacher lists enabling or prerequisite subject matter necessary to the clear teaching of the primary concept. The greater the detail, the more likely the teacher will identify concepts from other disciplines. As interdisciplinary concepts are identified, a curriculum model can be selected, and coordination between teachers in the team is initiated.

Beane (1976, pp. 3-4) described the resource unit as a method for the interdisciplinary team to plan actual instruction. Having identified a theme or problem around which to teach, the team identifies, and develops in a written plan the specific objectives, concepts, skills, materials, and evaluation for instruction.

The second phase of Jacobs' implementation strategy involves the proposal of a pilot study. Typically, the pilot study is small in scope. In phase three, teachers usually implement one unit and determine if its effects were positive. In the final phase, teachers use the integrated curriculum on a regular basis and refine the units they developed. These criteria suggest that treatment teachers for this study have prior experience with integrated curricula. TSM Integration materials have been implemented in a fashion similar to that described by Jacobs (LaPorte & Sanders, 1993, pp. 19, 21).

Kerekes (1987, p. 12) suggests that teachers implement units when students are tired of school or distracted by events or changes in the schedule. Good times include, before winter vacation, the days near the end of school, or half way between vacations. Integrated units should be taught at times when the student body needs a change of pace (Salinger, 1992, p. 43). Unfortunately, the scheduling of the pilot study and treatment for this study were beyond the control of the researcher.

Constraints to integrated curricula. Stevenson and Carr (1993, p. 11) insisted that the correlated curriculum described by Van Til, Vars, and Lounsbury is multidisciplinary, not integrated. However, this view is skewed, and it is entrenched in Stevenson's and Carr's vision of the integrated curriculum design called the core, a "virtuoso" or ideal curriculum. Realistically, when a group of educators combine to teach with an integrated approach, quite often they must work within the limitations of the unit of study or the subject-oriented structure of the school. The result is not "true" integration of discipline content but a correlated approach to integration (Bailey, 1991, pp. 36-37).

Merenbloom (1981, pp. 1-2) suggested that the crux of success in interdisciplinary instruction is the interdisciplinary team. Their ability to plan and deliver instruction is tied to the organization of the school. Team members need planning time in an already crowded schedule, and scheduling flexibility to arrange students within the team. Often the technology teacher is excluded from the team. Students go to technology education and other exploratory courses when the interdisciplinary team is meeting. However, communication can be facilitated by a designated exploratory team representative who is available to meet with the other teams in the school (Bergman, 1992, p. 189).

In mathematics and science classes, the teaching of related concepts may or may not coincide (Salinger, 1992, p. 45). Too often these teachers are confined to an inflexible schedule or sequence of instruction. The responsibility falls on the technology teacher, whose curriculum is usually more flexible at the middle school. Yet, the most organized interdisciplinary teams have only the capacity to correlate two or three integrated units in the course of a school year (George, 1982, p. 12).

In field testing their integrated curriculum materials, the Technology, Science, Mathematics Integration Project identified many limitations to correlating technology, science, and mathematics with interdisciplinary teams. The initiating teacher must find teachers and administrators who are able to work on the team and who share a belief in the philosophy of curriculum integration. The lack of common planning time especially for the technology teacher often led to disjointed implementation of TSM integration (LaPorte & Sanders, 1993, p. 19). Often the three teachers taught only three or four of the same students, leaving students who did not enroll in one or two of the team's classes without a holistic understanding of the concepts and skills taught. But ideal school structuring is not a prerequisite for TSM Integration Activities to be successful (p. 18). It is evident that constraints like those described acted upon the conduct of this study.

The Rationale and Nature of Problem Solving

Hatch (1988, pp. 88-89) defined a problem as something that keeps the student from attaining an objective. He stated that it is important the student recognizes the existence of a problem, the student is motivated to reach the obstructed objective, and the problem makes the student utilize various resources to solve it. Hatch stated that problem solving is the "process of seeking feasible solutions to a problem" (p. 89).

Suppose that a student is told to generate electricity using wind power, and he or she is told that the device used must fit into a certain volume.

Certainly the student must combine a number of resources to actually generate electricity. These include an understanding of certain technological concepts such as material processes and wind collector design. However, the student must also use thought processes. His or her objective is to generate electricity from wind power, but there is not a wind collector provided; this is the obstacle to the objective. The means to build one are provided. The student must come up with a feasible combination of means to build the technological solution (a working model of a wind collector and generator) or problem solve. This is precisely the problem students were presented with in this study, and they had to problem solve.

There are many excellent models that have been used in this section to provide the basis for measuring the outcomes of problem solving and for understanding the nature of the process in general and in technology education.

The TSM Integration Project provides general guidelines for the use of their materials with a problem-solving approach. They suggest that teachers guide students in the application of science and mathematics principles during the design, execution, and evaluation phases of their approach to problem solving (LaPorte & Sanders, 1993, p. 19). Most importantly they give suggestions on how to evaluate the outcomes of technological problem solving using TSM Integration Activities (Sanders, 1993, pp. 57-59; LaPorte & Sanders, 1992, pp. 2, 4, 8-10).

Sanders (1993, p. 57) described TSM Integration Activities as materials that help students solve technological problems by applying science and mathematics. He characterized the TSM Integration Approach as being couched in the method of technological problem solving. Many aspects of the TSM Integration Activities and technological problem solving were primary instructional approaches used by both the treatment and control technology education teachers in this study. However, technological problem solving is not unique to the TSM Integration Project (Sanders, 1993, p. 57). Therefore, this review will focus on the more general aspects of problem solving and technological problem solving before returning to a description of the TSM Integration approach.

Bruner (1966, pp. 159-160) provided a rationale for the use of student problem solving and the ability of the student to solve problems as measurable outcomes of learning. His main complaint about traditional education is that it makes good use of telling students what to do without providing a reason for learning or a chance to apply what is learned. He maintained that the best way to provide a reason for learning was to engage students in problem solving. He predicted that teachers would be more likely to teach problem solving if they were provided good materials to facilitate the process.

Bruner also proposed research into interdisciplinary approaches to problem solving. "We...propose that special research be undertaken to devise and test certain 'transcurricular' courses that have as their object teaching of such methods" (1971, pp. 96-97). His premise is that if problem solving is such an important ability to develop and is such an important instructional method, it is worthwhile to investigate what enhances it in the laboratory.

The integration of technology, science, and mathematics is hypothesized to enhance this process because the student benefits from the principles and fundamentals learned in the various subjects. Such knowledge is important for the problem solver to self-correct or regulate inquiry. Information for self-correction has implications for measuring the outcomes of the problem-solving process. "...instruction uniquely provides information to the learner about the higher-order relevance of his efforts. In time...the learner must develop techniques for obtaining such higher-order corrective information on his own" (Bruner, 1966, pp. 51-52).

Similarly, if the student in technology lab expects a model car to accelerate due to the friction between its wheels and the road, and it only spins its wheels, his or her knowledge of friction in science class is a signal that the design of the car is inconsistent with the requirements of nature. The student had to have the opportunity to physically see how the car performed and the knowledge about friction to judge or evaluate its performance. The evaluation is based on the student's and/or the teacher's expectation for the car to accelerate.

Knowledge that relates to a student's criteria for judging the success of a solution should be taught near the time the criteria are applied (Bruner, 1966, p. 51).

For example, when friction is taught in science class, the student may fail to understand, perhaps not only the concept itself, but certainly its relevance to his or her needs. This suggests that, as a criterion for problem solving in this study, teachers on the treatment team should teach related concepts concurrently.

When a student sees a model car spin its wheels and understands the need for adequate friction, he or she is intrinsically rewarded or activated to investigate further (Bruner, 1971, p. 77). The student makes a second hypothesis based on the science concept. Adding weight to the car will increase its friction. The experiment of the science laboratory becomes research and development and invention in the technology laboratory. The timing of certain instruction and the opportunity to compare expectations to outcomes develops important attitudes about self-learning and inquiry (Bruner, 1977a, p. 20).

Even though a student discovered or learned of some concept, changing the context of - inquiry about the same concept - from the science lab to the technology lab revitalizes the problem-solving process and helps the student form images of what was learned. For example, having studied electricity in science, students have the opportunity to generate and measure electricity in technology class. Thus, there is a relationship between the TSM Integration Approach and the problem-solving process.

Bruner (1966, pp. 58-65) supported this idea when he described a mathematics experiment in which blocks of wood were first used to teach the mathematics concepts of factoring. Students were allowed to discover similarities in the ways they could symmetrically arrange the blocks. The problem was to arrange the blocks symmetrically using different arrangements. The measures of success were that the arrangements were symmetrical, and the researcher was interested in how many symmetrical arrangements the students could create. The blocks were physical representations of the factors students were learning. For example, given six blocks, the students could have made several symmetrical arrangements: one arrangement of six; two rows of three blocks; three rows of two blocks; and six rows of one block each.

Next in the Bruner experiment, the students were given a new problem of balancing a scale with weights, and they discovered the same relationships as in the first problem. The balancing of the scale was a physical measure or indication of the students' conception of symmetry and indirectly of the root conception of factoring. Each time the students were not told they were still studying factoring; they identified this through the manipulative exercises.

They did not perform as well in the first exercise as in the last. At first they were not able to abstract the problems they solved to embody the concept of factoring. The abstraction required a series of problems or activities (Bruner, 1966, p. 65). If students are to generate increasing amounts of electricity by manipulating a wind collector they built in technology education, they will not immediately abstract the concept of generating unless they physically measure the electricity produced. After tries at changing the power output of their generators they understand that certain variables control this previously unseen thing called electricity. Being able to "do" technology allows students to finally internalize its concepts and constructs.

"Doing" technology: real experience in

learning. It is necessary to answer the questions why physically doing things (and in particular "doing" technology) in school is important, and what is meant by technological problem solving because these are important elements of this study. Dewey (1917, pp. 182-183) believed that the environment of the school is an artificial one that bears none of the circumstances of real life and therefore diminishes the opportunity for students to inquire and solve relevant problems. His prescription for relevant problem solving was experience and the resources necessary to carry out hands-on instruction. Instead of being told knowledge, students invent and inquire (pp. 185-189).

There are great differences in the way reading teachers teach and technology teachers teach, but the fact remains that one must read to learn reading. Technology is a body of knowledge and the systematic application of resources to produce outcomes in response to human wants and needs (Savage & Sterry, 1990, p. 7). To learn technology, one must produce technological outcomes in response to needs. As previously stated, Lux (1984, p. 18) set a criterion for technology education instruction and curriculum development that, "Practice is an essential but not sufficient characteristic of technology," meaning that a theoretical basis must exist relating to the learning and practice of technology. This researcher contends that the opposite is equally important - theory/abstraction is an essential but not sufficient characteristic of technology. To confirm theory one must apply and test it. What LaPorte and Sanders (in press) devised as a criterion for technology teacher education is pertinent to secondary education. "What is needed are educational experiences in which 'doing' technology is the modus operandi...And theory without practice is mere intellectual exercise" (in press).

Bruner (1977a, pp. 29-30) provided an illustration of the subtle difference in doing and knowing. He used an example of teaching the writing styles of literary authors. One could contrast authors' styles by reading their works, "yet final insight into style may come only when the student himself tries his hand at writing in different styles." In technology lab a student could build a wind collector to generate electricity and change its design according to science theories that should improve its output, but until the student measures the actual output of the wind driven generator all theories are just that - theories.

A final and well put characterization of this discussion comes from a teacher of elementary science (Brodie, cited in Haury, 1992). "Vocational education has always understood that if you want...to learn to repair an automobile, you need an automobile to repair...Likewise, I...believe we are learning that...to truly teach science, we must 'do' science" (p. 3). Among other things, to truly learn technology students must do technology and essentially produce outcomes to meet human wants or needs.

Technological problem solving: a process of technology. The scientific method is to the scientist as technological problem solving is to the technologist and the engineer (Savage & Sterry, 1990, p. 12). Technological problem solving is the problem solving process, described from a general perspective above by Bruner and Dewey, combined with the processes of technology in engineering, architecture, industrial workshops, research and development laboratories, the home, the office, and field, etc., and certainly the technology education laboratory. The processes of technology employed to solve problems of human need or want characterize this method.

These technological processes are also broad, but they can be characterized by what they change and the context in which they are employed (Savage & Sterry, 1990, pp. 16-19). Resources include concepts such as materials, tools and machines, information, energy, etc. The contexts in which the processes are employed include producing, communicating, transporting, etc. In producing an automobile, a manufacturer will use tools and machines to form, separate, and combine materials. When safety and economy are the design foci, the problem requires the engineer to consider many things. Is the material light weight enough to improve milage yet strong enough to withstand an impact? The automobile will have to be milage tested and crash tested. This is the feedback of the technological method model (Savage & Sterry, 1990, pp. 13, 15, 18).

In the technology education laboratory, the student is both engineer/architect and technician/worker. Often actual artifacts, products, or outcomes are produced in the laboratory. However, it is sometimes necessary to simulate or simply model the outcomes of technological processes (Tracey, 1990, pp. 138-143; Roth, 1987, p. 14). Nevertheless, it is necessary that the student is able to see life-like results in a simulation or model. For example, a student must be able to crash test a model car to determine the extent to which his or her concern for simulated safety is realized in its design and fabrication. Solving technological problems could then be thought of as a measure of achievement in technology education much in the same way a mathematics test measures mathematical achievement in math class.

Models of problem solving and their outcomes. Models of problem solving, "the heuristics of discovery" (Bruner, 1977b, p. 194), provide the structure of inquiry, yet a knowledge of how people solve problems and indicators of the process are required because technological problem solving was the primary instructional method for this study and the TSM Integration Activities.

Johnson (1994, p. 27) warned that the use of stage models of problem solving were unrealistic and ineffective for teaching students problem-solving skills. A stage model is similar to Polya's (1948, pp. 5-6) four stages for solving a mathematical problem: (1)

Understanding the problem; (2) Devising a plan; (3) Carrying out the plan; and, (4) Looking back. Johnson cites research studies where students were taught problem-solving stages but did not use them or were led down dead ends in the process. He warned that explicitly teaching students certain behaviors associated with problem solving did work according to research examples but that curriculum guides in technology education that suggest teaching stages to students may not help.

Among some of the behaviors Johnson (pp. 27-28) outlines that are most significant to this study are:

"• Obtain problem information via the senses.

• Use technical devices to collect problem information."

• Use charts and graphs to simplify the problem.

"• Use planning, predicting, evaluating..."

According to Bruner (1977b, p. 194) the student has intrinsic attitudes or a built-in sense of how to pursue problem solving. Yet, he also recognized the need for structured discipline-based inquiry techniques. Bruner's belief is the student benefits best when he or she is provided instruction leading to a coalescence of these two possibly divergent approaches.

In view of the intuitive nature of student problem solving, the uses of a problem-solving model are primarily to help the teacher identify opportunities to structure the students' endeavor and to programmatically blend the methods of formal inquiry of the technology, science, and mathematics disciplines.

Bruner, Goodnow, and Austin (1956, pp. 128-131) presented the results of an experiment they conducted on college students (for general discussion of results see pp. 231-246). It was a study of the strategies subjects employ to solve a problem (p. 246) or attain a concept, also known as reception. The subjects were not tutored in problem solving prior to or during the treatment. Given the task of identifying or attaining a concept unknown to the subject, he or she was shown a succession of images that either represented the concept or did not represent it. Subjects had no control over the sequence in which they were shown the cards, but they were told whether or not the unknown concept was represented by the card. In essence, the subject must internally develop a hypothesis that helps determine how or how not a card exemplifies the unknown concept in order to identify the concept. Additionally, the subject must be able to change hypotheses when one has failed.

In this process, the researchers knew what concepts were represented by the images on each card, and they could tell if the subjects had attained the concept in each instance because they either stated the correct concept or could not. The degree to which subjects changed their hypotheses or strategies could be determined by their sequence of responses.

In a similar manner, say a student were to build and test a wind collector to generate electricity in technology education class. A main part of the assignment is to improve its power output. In order to tell if the student is successfully hypothesizing changes to improve the output, the output must be measured or observed.

In the Bruner, Goodnow, and Austin study, most subjects tended to use one of two ideal strategies beyond that expected by chance, they tended to use the same strategy from problem to problem, and did not act randomly (p. 140). In the technology education problem example above, other indicators of deliberate strategies might extend beyond direct measurement of power output to include materials used or pitch angles of the blades on the wind collector.

The study on concept attainment has implications for a model of problem solving, and suggests criteria for its use in this study.

- The human has an internal structure to guide the process and makes an initial prediction or hypothesis.
- A problem-solving model must allow the freedom to change hypotheses when new contingencies are encountered.
- It must provide iteration or the solver will not attain the concept or best solution.
- Real-life circumstances warrant the use of record keeping to free the memory.

In the Polya (1948, p. 12) model, the student should prove that each step is correct. While his model is for use in mathematics, there is a similarity in the this approach and the trouble shooting process that forms a sort of sub-loop in the construction phase or implementation phase of a technological problem solving episode.

For example, if a student decided that a working model of a magnetic-levitation vehicle would provide the best solution to a transportation problem, then he or she might as a first step in carrying out a plan select light-weight materials. Second, the student might try to balance the chassis and position the magnets. These might be two steps in a plan.

Polya wants students to prove each step because the student might not detect problems until the end of the process. In the magnetic levitation problem, the student may also have to hunt down or trouble shoot mistakes. Even though the chassis was balanced in an earlier step in the process, the addition of a motor or other hardware to the vehicle may either cause the chassis to become unbalanced or could be an indication that the magnets were positioned incorrectly. There may or may not be a way to check for earlier mistakes until later ones reveal themselves in a technological solution. Such an instance points to a need for an emphasis on trouble shooting and the control of variables in the technological problem-solving process. A very important aspect of trouble shooting and checking at intervals for mistakes in technological problem solving is the reality that students must be able to evaluate solutions based on their expectations for performance. The magnetic levitation model could not be tested unless the student could place it on the test track.

Polya (p. 14) contended that there is a correct answer even though there may be different algorithms or solutions to arriving at it. In technology, there could be different paths to a solution and different correct answers. Two students may get their magnetic-levitation vehicles balanced using different applications, they might even look different, but the end result is that they both got them to travel. In this study, two technology students might have done different things to make their wind collectors improve, but they can tell they improved because they measured an increase in the power output.

The Project 2061 (1989, pp. 147-149) offered suggestions about how teaching and learning in science should reflect the nature of scientific inquiry. Their suggestions promote the coalescence of the intuitive nature of the student and formal inquiry of the discipline. They say science teaching and learning should begin with questions about nature. It should involve students in measuring, recording, and concluding about phenomena within their perception and experiences.

Students should base their conclusions on evidence. For example, if a student wanted to experiment to see how much mechanical advantage a simple machine provided, he or she would measure the distance the machine moved and the respective forces involved using a meter stick and a spring scale.

Problem-solving models in technology education. The premise is that scientific inquiry characterizes science, and learning science in the schools necessarily requires conducting scientific inquiry. Savage and Sterry (1990, pp. 12-15) maintain that the same is true for technology. The "Technological Method" is the manner in which technology is developed, created, implemented, and used. It is characterized by Savage and Sterry as having inputs, processes, and outputs. Its use as a pedagogical problem-solving strategy is more limited than its use in understanding one aspect of the nature of technology. It is a problem-solving approach in so far as technology itself solves problems.

Israel (1992, p. 13) believes that technology is not defined by one particular method of inquiry or that technology is an outcome of one particular method of development. Nevertheless, the most important aspect of the Technological Method model is that it acknowledges the importance of employing real technological processes in the creation of technology, and the solving of technological problems is at least one characteristic of the discipline (Bensen, 1980, p. 14).

Hatch (1988, pp. 91-93) made a distinction between the old project method of industrial arts and the new activities of technology education as an introduction to his perspective on problem solving in technology. The argument that purposeful activities are superior to simply building things is a sound one, but Hatch's vision of activity and problem solving are not well defined, but he certainly believes ill-structured problems are important. Sellwood (1989, p. 7) described the use of paper to model technological solutions to problems, but models made from paper and styrofoam could be made by any student under teachers from any subject area in the school.

While Hatch promotes solving ill-structured problems, critical thinking and divergence, and Sellwood promotes paper and cellophane tape (primarily for the elementary school) they offer no recognition of the criterion that Lux (1984, p. 19) observed as important; that practice in the absence of theory is an insufficient characteristic of technology. His premise of "thoughtful doing" recognizes that if technology education is to interpret technology, then teaching problem solving without acknowledgement of other physical technological processes is inadequate for this study. Examples of such processes would include changing the form of materials, crash testing life-like model cars, and measuring electrical output, in highly structured problems as opposed to the ill-structured problems; popular in a variety of general education subject areas.

Hatch (pp. 89-91) rejects even a secondary need for convergent thinking and highly structured problems. His preference is for students to work on ill-structured problems, thus fostering creative problem solving and divergent thinking. This would be good for general problem solving but inadequate for technological problem solving. In any technological problem of even an ill-structured nature there will be a sequence of highly structured problems related to the "doing" of technological processes required to solve the ill-structured problem (Dugger, 1993; Shaw & Reeve, 1978).

Waetgen (1989, pp. 6-7) developed a simple problem-solving model for technology educators. In technological problem solving, a looping back in the process is important for optimally developing technological solutions and for improving them. Such looping is built in at all stages of the process. The model uses six stages all of which are assigned basically the same importance. The six stages are (pp. 5-7):

1. Recognizing the situation in which the problem is set and the constraints.
2. Think about many solutions and gather information or "anything that reduces uncertainty" (p. 5).
3. Hypothesize the best solution.
4. Build solutions, but Waetgen emphasizes the importance of having students keep track of how each sub-task in this stage is working - evaluation. The student must compare intermediate outcomes with predictions.
5. When the original hypothesis fails, formulate a new one.
6. Students must decide whether or not they met

their objectives for the solution. For example, did the student improve the output of a generator?

This model does not satisfy the need in this study to guide the application of science and mathematics principles during the process.

Another model that recognizes the need to employ technological processes was proposed by Braukmann and Pedras (1990, pp. 21-23). It is similar to Waetgen's, but those stages that need emphasis are listed below:

2. Establish criteria for the solution. For example, determining that a safe design for a model car is its ability to protect an "egg" simulating a passenger in a crash test or improving the amount of power output on a student-made wind collector.
3. Research previous or similar solutions.
6. Make working models.
7. Evaluate the implemented solution.

Johnson (1992, pp. 35-37) supported the criterion of structure. "There appears to be a growing consensus among researchers and teachers that it is beneficial to explicitly and directly teach students both the concept of metacognition and the use of the metacognitive process" (p. 37). He does not mean memorizing stages meant to guide the instructional behavior of the teacher, but those strategies that help students self-regulate the problem-solving process within their cognitive structures.

Maley (1992, pp. 4-17) outlined and described ten characteristics of effective problem-solving activities. Two are listed below:

3. The problem-solving procedure is systematic and analytical (p. 6).
4. "The problem solving activity is a holistic approach making effective use of inter-disciplinary involvements wherever such activity is relevant to the conduct of the problem(s) being solved" (p. 10).

Shaw and Reeve (1978, p. 7) developed a model of the "Design Process," a problem-solving model. It acknowledges the nature of technological problem solving as dependent upon convergent thinking. Students use divergent thinking in the process until they begin rejecting possible solutions and narrow their choices. This model provides no guidance for the application of mathematics and science principles.

The TSM Integration Project related to problem solving. Sanders (1993, p. 57) described curriculum enhancement materials that he and LaPorte developed. The materials are a set of technology activities that integrate technology, science, and mathematics at the middle school level. The structure of the materials is useful in designing a model of problem solving as an instructional method in an integrated curriculum. Sanders also provided suggestions on how the success of the integrated technological problem solving is evaluated.

The span of the problem-solving process is couched in the three phases of instruction; the design phase, the construction phase, and the evaluation phase. This structure assists students in maintaining the problem-solving process from one phase to the other. For example, during the design phase the student or group of students need to choose the best solution. Based on the literature, divergent thinking may be more appropriate in the design phase, and convergent thinking may be more helpful during part of the construction phase. The three-phase structure also alerts students when appropriate applications of mathematics and science are needed. For example, the student may need to apply principles of drag and friction (science) during the design of an aerodynamic vehicle and graph the results of its performance (mathematics) in the evaluation phase.

Sanders (p. 58) presented a TSM Integration Brief for a unit or activity called "Capture the Wind." He presented the problem as an assignment to "transform wind energy into electrical energy." The TSM Integration Brief for the unit presents students with the criterion reference for success in solving the problem; the measurement of the power output of the wind generators for which the students built collectors. The higher the power output, the more successful will be the student at solving the problem. The Brief states, "The solution that generates the highest average wattage from these tests will be deemed the winner of this challenge" (p. 58). Unlike the ill-structured problems promoted by Hatch, the TSM Integration Activities are more structured and involve constraints imposed on the design and construction of the solution (LaPorte & Sanders, 1993, p. 18).

Sanders (1993, p. 59) described the process for testing the solutions in the "'Challenge' phase of the activity." The wind collectors are mounted on a generator that is hooked up to two multimeters. They simultaneously measure voltage and amperage. Gathering the data from the meters, students analyze it in mathematics and return to science class to make new hypotheses on what will improve power output. "The data collected during each challenge is critical to the problem solving that takes place" (p. 59). Therefore, running the Challenge more than once allows students to apply science and mathematics to improve their technological solutions.

LaPorte and Sanders (1992, pp. 2-10) provided other ideas on how to evaluate the success of the problem solving. They are listed below:

- "...using math as a tool for determining effective solutions" (p. 2).
- Students develop conceptual understandings based on their observations of how solutions perform. "...they will understand conceptually why a 'fat,' [sic.] boat riding low in the water travels more slowly than a streamlined

boat" (p. 4).

- "The Challenge portion of the activity could be run in [all three classes]. This would give student teams a chance to redesign and rework their solutions and provide a richer set of data for evaluation purposes" (p. 8).
- "The emphasis should be on process rather than product" (p. 10). Here the measure of success focuses not so much on whether or not the problem was solved but that the students tried to apply science and mathematics. "It is entirely possible that 'good science' may not automatically produce a winning science, and vice versa" (p. 10).

Therefore, some evidence should be collected as to the extent of science and mathematical applications. For example, a student may have discovered that a certain pitch angle will make his or her wind generator turn faster. Attributes of the solutions that reflect science and mathematics instruction/learning may serve as criteria for evaluation.

Evaluation and Assessment of Students

The methods used to score student work in technology education are typically different than those used in traditional classroom-based school subjects. As such, it is necessary to review the consensus of accepted evaluation and assessment in the field of technology education.

Wescott (1993, pp. 167-168) distinguished assessment from evaluation. Evaluation is a judgement of how well a student has met certain instructional or learning objectives. Assessment is a judgment of how effective instruction was in advancing a student's learning beyond the level he or she was at prior to a learning episode. Assessment can be thought of as a measure of where a student is on a continuum of achievement in some area of study. Another perspective in understanding assessment is thinking of it as a way of determining the educational needs of students (McLoughlin & Lewis, 1986, p. 3). Evaluation, on the other hand, can be thought of as a measure of the degree to which a student has achieved a specific objective.

Evaluation involves four basic steps. First, identify the behavioral outcomes or changes in student behavior that are desired; objectives. Second, plan and deliver instruction that is referenced to the objectives. Third, measure student progress toward stated objectives. Fourth, use the results to improve instruction (Wescott, p. 168).

The measurement of the student's progress toward objectives can be accomplished in a number of ways. The teacher can test students, observe them, or get them to write or report about themselves (Wescott, pp. 182-183). A portfolio can be thought of as a form of self-reporting. Gilberti (1992, pp. 254-256) stated that the construction of projects, student demonstrations, and other activities are good alternatives to written, formal testing. No matter what methods are employed, the student should understand how he or she will be evaluated. Gilberti suggests that the use of a variety of evaluation techniques is the best approach.

The portfolio could be an important means for evaluating student learning in the short term and assessing achievement in the long term. Collins (1991, p. 295) stated that the portfolio should reflect the practices of the field that are relevant to the instructional objectives. Should a technology education student be assigned a technological problem to solve, and the objective is for him or her to derive an understanding of problem solving in the way a technician, inventor, or engineer practices it in the field, then the portfolio should provide evidence of this understanding.

By doing this, the portfolio becomes a means of authentic assessment. Mitchell (1989, p. 5) stated that authentic assessment is characterized by the question, "Is this what we want students to know and be able to do?" Authentic assessment measures real practice, processes, understandings, and knowledge of the field (Collins, p. 295). The portfolio should reflect this purpose. The portfolio should reflect the grade level of the student, the discipline, and the interests of the student. Only key evidence of achievement belongs in the portfolio; it should not be confused with a notebook and become cluttered with every thought a student has during class (pp. 297-298).

Haertel (1991, p. 242) stated that projects and laboratory activities tend to end with scorable products and artifacts. These end products should represent the results of practices and processes in the field. For example, in solving a technological problem, some student-built device may represent the solution or act to affect the solution of the problem. Subjective ratings of such outcomes is unavoidable, but objectivity can be added to the process by developing a rating scale and making sure students understand how the ratings are applied to their work.

Haury and Rillero (1992, pp. 13-15) outlined the evaluation of hands-on learning. One simple approach to evaluating student processes is asking the student why certain events are occurring, interviews. Next, if the objective is to apply mathematics and science principles, then the evaluation task or hands-on evaluation should require their application. Bloom, Engelhart, Furst, Hill, and Krathwohl (1956, p. 125) stated that in measuring a student's ability to apply knowledge, the context of the problem should be different than that in which the knowledge was learned. The evaluation of skills should not require traditional testing, and the scoring should measure performance not content (Haury & Rillero, p. 14).

The Technology, Science, Math (TSM) Integration Project

As previously stated, the TSM Integration Project developed curriculum enhancement materials that integrate technology, science, and mathematics in the middle school. The Project is funded by the National Science Foundation (LaPorte & Sanders, 1993, pp. 18-19). Adapted versions of one of the TSM Integration activities were used in this study. The materials are not a curriculum but a collection of technological problem-solving activities that may be inserted within the existing curricula. The 16 TSM Integration Activities, as they are called, basically correlate the instruction of the three teachers who work as an interdisciplinary team as described by Van Til, Vars, and Lounsbury (1961, pp. 90-96). Jacobs (1989b, pp. 15-18) developed two particular models of curriculum integration that happened to describe the TSM Integration Approach. The TSM team teaches related content at about the same time during the instructional unit. Jacobs described this arrangement in the model called "Parallel Disciplines." However, the TSM teachers might only use the TSM Integration Activities one or two times in a school year (LaPorte & Sanders, p. 18), and any given activity requires one to three weeks to implement. The science and mathematics teachers spend only a couple of class periods when they are new to the TSM Integration approach (LaPorte & Sanders, 1992, p. 7). This approach is described by Jacobs as the "Interdisciplinary Unit." The overall objective of the TSM Integration Activities is to require the application of science and mathematics principles and concepts to solve the technological problem at hand (LaPorte & Sanders, 1993, p. 18).

The TSM Integration Activities, in their piloted form, provide a resource for each of the technology education, science, and mathematics teachers as the most substantial parts of the activity materials. They include content if it is not typically found in textbooks. Similar materials were described by Beane (1976, pp. 3-4) as being essential to planning and instruction in integrated curricula. The other portion of the materials intended for use by the teachers is a section that lists references and supplies, describes the sequence of instruction, and describes the activity in general terms. The other section of the activities is the previously mentioned "TSM Integration Brief" that sets up the technological problem for students (LaPorte

& Sanders, p. 19).

The one-page brief is given to the technology education students at the beginning of the unit. The rest of the activity materials are used by the teaching team. The brief is divided into five sections. The "Situation" provides background and a setting or context for the technological problem that the student will solve. The "Problem" explains generally what needs to be accomplished through the problem-solving process (Sanders, 1993, p. 58). The "Constraints" explains to the students additional and specific requirements of the problem solution and other specifications within which the students must work (LaPorte & Sanders, 1993, p. 18). For example, in the TSM Integration Activity, "Power Boat," students are to design model boats as a solution. The boats must be built no wider than specified in order to fit in a testing device. The "Challenge" describes how the technological solutions will be evaluated (Sanders, 1993, p. 59). And, the "Documentation" section lists what students must record in their portfolios (p. 58).

The aforementioned instructional sequence chart in the overview of the teacher resources shows the team what instruction should include in the three classes, the sequences of the instruction, and the phase of instruction in which the specific content is delivered; the design, construction, and evaluation phases that were described on page 94 of this review.

These materials and the approach to integration they support were field tested for three years between 1991 and 1994 at over thirty middle schools nation wide. Substantial data on teacher and student perceptions of the materials and the their implementation have been collected, but they are currently being analyzed (LaPorte & Sanders, 1993, p. 21).

Research in Curriculum Integration and Related Issues

Gordon Vars (1991, p. 15) cataloged over 80 studies on the effectiveness of integrated curricula and programs and reported that most were either equal to or better than traditional approaches. However, the most frequent results are the lack of significant differences in the groups being studied. There are, nevertheless, some studies that suggest an interdisciplinary approach may be better in affecting improved student achievement.

Included are studies that are related to curriculum integration but are not within the specific scope of this study. A brief review will provide some insight into the effects of curriculum integration in general and into certain related issues such as hands-on instruction, problem solving, integrated core course designs, and team teaching of integrated curricula.

Research on the effects of hands-on instruction. The use of hands-on instruction was proposed for this study. Studies outside the field of technology education can only give the researcher and educators in the field an idea of how their findings relate to technology education. Statistically speaking they are not generalizable, however, they are of a certain value. "...it is quite likely that the findings reported...on the value of hands-on activity in increasing cognitive understanding in mathematics and science would be [intuitively] generalizable to technology education" (LaPorte & Sanders, in press).

Saunders and Shepardson (1984, pp. 3-4) compared the science achievement and cognitive development of sixth grade science students. The treatment group (N=57) received instruction with an emphasis on hands-on instruction, discovery, invention, and exploration for forty-five minutes a day for nine months. The control group (N=58) received formal instruction and were not involved in experimentation and did not use laboratory equipment. They found statistically significant differences in favor of the treatment group for both science achievement and cognitive development. Their study suggests that an active concrete approach to instruction may be superior to traditional lecture and demonstration.

Glasson (1989, p. 121-123) measured the science achievement and problem-solving ability (in the algorithmic/mathematical sense) of ninth grade science students, and determined if reasoning ability and prior knowledge are predictors of the dependent variables. The treatment group (N=27) received hands-on experimentation for the three weeks, and the control group (N=25) received demonstrations on the same science content. There was no statistically significant difference in the science achievement of the two groups. However, there was a statistically significant difference for problem-solving ability in favor of the treatment group. Both reasoning ability and prior knowledge appeared to be significant predictors of problem-solving ability.

Korwin (1986) compared the cognitive achievement of eighth grade technology education students and their retention of concepts. The treatment group (N=25) received hands-on instruction on a technology topic for two weeks. The control group (N=25) received only illustrated lecture. Differences in achievement were statistically significant in favor of the treatment group. However, there was no difference in the two groups' retention of the knowledge as measured after a two week period following the treatment. Korwin's study suggests that students may benefit from the hands-on approach to technology education. The down side to this suggestion is that Korwin's study is the only one in the technology education field to measure the effects of hands-on instruction at the secondary level (LaPorte & Sanders, in press).

von Eschenbach and Ragsdale (1989, pp. 225-227) used hands-on treatment (referred to as experimental learning) with second graders (N=25) who studied an integrated unit on mathematics and social studies for 10 weeks. The control group (N= 23) studied mathematics and social studies separately through traditional lectures.

The study compared the mathematics and social studies achievement of the groups. Statistically significant differences were found in favor of the treatment group. This study suggests that students may benefit from curriculum integration and hands-on learning.

The results of these four studies may lend support for the use of hands-on or activity-based instruction in the school subjects studied including technology education. All four found at least some significance. However, three of the four studies used relatively small samples.

Research on problem solving in technology education. Problem solving was an important consideration in this study. A review of research related to it is warranted. Doyle (1992) conducted a delphi study to identify components of the technology education laboratory and program that are important in delivering technological problem-solving activities. The most important factor was information resources. This included computers and computer networks, databases and other computer applications, access to libraries, and in-lab books and references. The second-ranked factor was opportunities to take field trips and the like, participation in after school experiences in the field of interest, and guest speakers. The third highest ranking went to the availability of machines and tools for processing materials. The results suggest that any program that teaches students technological problem-solving should primarily have available information resources, contact with real-life related opportunities, and a good physical plant; this includes the sites used in this researcher's study.

Sheldon (1991) compared the pretest and posttest scores of 43 middle school technology education students as a measure of change in creativity. The treatment was a technology education instructional unit designed to foster creative problem-solving. No statistically significant differences were found.

Scanlin (1985) compared problem-solving ability of public school seventh and eighth grade industrial arts students and private school seventh and eighth graders (control group, N=32) before and after the public school group (treatment group, N=39) took industrial arts. The study did "...provide some support for the hypothesis that industrial arts classes help students to become better problem-solvers." The results suggest that industrial arts education uses methods of instruction that may benefit students.

The Sheldon and Scanlin studies contradict each other. Yet, Scanlin's report of support for the hypothesis that technology education may foster problem-solving skills is encouraging.

Research on the effects of small group learning in technology education. Those students learning TSM Integration Activities may be placed into small groups to work on technological problems. Research in small group learning was important in terms of what to expect from individual students' learning with the groups. Perreault (1983) studied the effects of small group learning on the cognitive achievement of seventh grade industrial arts students. Students were pretested and after six weeks tested again. The treatment group worked in small groups and the control group subjects worked individually. Statistically significant differences in achievement in favor of the treatment group were found for recalling knowledge and understanding knowledge. No differences were found in the groups' ability to apply knowledge.

The results of this study suggest that it may be important to work in small groups in a correlated curriculum integration arrangement. If the participating teacher do not share all of the students in common, those students who are shared should be distributed to participate in each group. Because there is a science student in a group of students who otherwise are not taking science from a participating science teacher, the belief is that the science student will contribute his or her science knowledge to the group effort (LaPorte & Sanders, 1993, p. 18; Sanders, 1993, p. 59).

However, the Committee on Research in Mathematics, Science, and Technology Education, Commission on Behavioral and Social Sciences and Education, and the National Research Council (1985, p. 28) cited evidence that not every student in the group benefits. "...it appears that cooperative groups do not necessarily ensure equal exposure to learning. Differential treatment [of group members] can come as readily from peers as from a teacher" (p. 28). Students involved in group learning should be taught to employ strategies for working as a group.

Research on the effects of interdisciplinary team teaching. In the present study, teachers had to work together. Is team teaching in any form beneficial? The following studies are on the effects of team teaching, however they were teachers of different subjects, and they did not attempt to correlate or make connections among subjects represented.

Fuller (1977) conducted a delphi study to determine indicators of success for middle school interdisciplinary teams. After three rounds, there was very little agreement with the exception of the team teachers having common planning time and a place to conduct planning. This finding suggests that any team effort in curriculum integration should provide the opportunity for common planning; including those participating in the current study.

Jester (1966) conducted a study on the achievement of eighth grade students in language arts and their achievement in social studies. There were 197 students in the treatment group and 262 students in the control group. The treatment was team teaching, and the control was traditional instruction by individual teachers. Significant differences were found in favor of team teaching for language arts, but no difference was found for social studies. These results suggest that team teaching may positively effect language arts achievement.

Noto (1972) compared the effects of team teaching on seventh graders' basic academic skills and the basic skills of traditionally-taught students. The treatment group consisted of 222 students and the control group consisted of 178 students. Statistically, significant differences were found in the basic academic skills of the groups in favor of the control with the exception of reading skills. Results suggest that team teaching may have a positive effect on reading skills.

Ernest (1992) compared the effects of team teaching on seventh grade students' basic academic skills and the basic skills of traditionally taught students. Statistical significance was found in favor of the control group for social studies achievement, but no other significant differences were found. Significant school x group interactions may suggest that the school students attend may be more important than the treatment in affecting achievement in academic skills.

The results of the Jester, Noto, and Ernest studies may suggest that simply teaming teachers has only limited effects on the achievement of students. They may also suggest that teams must do more than simply meet to discuss the needs of students and conduct the day-to-day business of the school.

Research on the effects of team taught integrated curricula. The following research studies and one research synthesis focused on the treatment of subjects with team teaching. All three studies included teaching integrated content. That is to say the teachers taught together in the same classroom at the same time, but each was responsible for delivering instruction in different subject areas.

Gamsky (1970, pp. 42-44) compared the subject matter achievement of ninth grade English and history students after one year of treatment. The treatment group (N=74) received integrated instruction in the two subject areas by a two-teacher team in a two hour block of time daily. The control group (N=71 received traditional subject-segregated instruction from individual teachers. There was a statistically significant difference in the randomly assigned groups in history achievement but no difference in the groups for English. This suggests that students achieve better in history when it is integrated with another subject and team taught.

Cotton (1982, pp. 2-4, 10-13) compiled a research synthesis of studies measuring the achievement of students in interdisciplinary, team-taught integrated courses. Nine studies were at the middle school level. Each study compared the achievement of team-taught integrated curriculum groups to students taught by one teachers in separate-subject classes. One of the nine studies favored the treatment group, one favored the control group, and the remaining studies found no statistically significant differences.

Graw (1981) studied groups of elementary students who received integrated instruction in mathematics and language from teams of teachers and those who received subject-oriented instruction from individual teachers. No significant differences were found.

The results of these studies are not promising and they may suggest that if two teachers are teaching in the same classroom, they might need to teach concurrently instead of simply taking turns at presenting their respective subject content. There could be other plausible reasons for differences in significance outcomes such as differences in the skills and experience of the participating teachers.

Research on the effects of integrated curricula. The following studies researched the effects of integrated curricula that followed nearly the same approach as the present study with a few exceptions. The review of these studies gave an idea of what to expect from the integration of technology education, science, and mathematics at an intuitive level.

Shann (1975, pp. 1-3, 8) reported the results of a study measuring the effects of the Unified Science and Mathematics for Elementary Schools curriculum instructional units. The units of curriculum materials integrate science and mathematics. Sampling units consisted of 37 treatment classrooms compared to 34 control classrooms. Control groups received traditional, subject-oriented instruction. On average, treatments were administered one and one-half hours daily, three days a week for 12 weeks. Dependent variables on pretests and posttests were basic academic skills and problem-solving ability. While students were said to be excited with the treatment, no statistically significant differences were found. Shann concluded that the USMES curriculum materials did not inhibit student growth in basic skills.

Anderson (1992) compared the effects of a particular integrated instructional method (treatment) in mathematics, economics, and science on the problem-solving ability of high school seniors and seniors whose integrated instruction excluded the particular method (control). The treatment "group's instruction included specific strategies for building connections among the three subjects. The second group received no connection building instruction." The pretest and the posttest consisted of problem-solving measures that required integration of the content from the three subjects. The particular method of connection building had no statistically significant effect on the problem-solving ability of the treatment group. Evidence seems to suggest that it is ineffective to deliberately focus instruction on the connections among subject areas when the objective is to improve problem-solving ability.

Bishop (1960) compared the effects of an integrated high school curriculum of English and social studies (known as Combined Studies, the treatment) on the achievement of students in grades nine through twelve and students in traditional English and social studies.

Most of the 902 (N) students participating in total were in the control group. Statistical significance was not mentioned. However, Bishop concluded that the Combined Studies students performed as well or better in English and social studies than students in traditional classes. The results might suggest that curriculum integration has a positive influence on the English and social studies achievement of students.

Ballard (1982) studied the achievement of 84 junior college students who used interdisciplinary materials that integrate biology, chemistry, and mathematics and the achievement of 554 students who did not use the materials. The treatment was used to supplement regular instruction. The study lasted three years. No significant differences were found. The results suggest that interdisciplinary materials that integrate curriculum content and are used to supplement instruction may not be effective at improving achievement in biology, chemistry, and mathematics.

Clayton (1989) compared the effects on achievement of ninth grade physical science student who received supplemental science-related mathematics instruction prior to a science unit and the achievement of students who did not receive supplemental instruction. She found statistically significant differences in favor of the treatment group for improvement in science-related mathematical skills but no significant differences for science achievement. The results suggest that integrated mathematics and science materials used to supplement instruction may improve the specific skills taught in the materials. It also seems to contradict Ballard's findings at an intuitive level, however, no valid comparisons between the two studies can be made as one studied junior college students and the studied ninth grade students.

Mermoud (1979) compared the effects of an integrated social studies and language curriculum on the achievement of 225 junior high school students to 225 students who received traditional, subject-oriented instruction. One of the treatment subgroups had significantly higher achievement scores in language, but no statistical significance was found between any other groups. This study suggests that the integration of language and social studies may be no more effective than the traditional approach. This conclusion contradicts previously cited studies.

Bruce (1973) compared the mathematics and science achievement of six classes of third grade students and six classes of fifth grade students who received integrated mathematics and science instruction (in its true form), six classes in each grade level who received integrated instruction that was correlated, and six classes of students who received traditional subject-oriented instruction in mathematics and science in the two grade levels. There were not significant differences among the three groups at either grade for mathematics achievement. Lower ability students in two of the treatment groups achieved at statistically greater gains in science than higher ability students. The results suggest that true mathematics and science curriculum integration and curriculum integration in the form of correlation may be effective in improving the science achievement of elementary students who are assessed at low ability levels.

Brunk and Denton (1983, pp. 43-44, 46) compared the conceptual understandings in music, science, and social studies of 317 first graders who received integrated instruction in the three subjects and the conceptual understandings of 102 first graders receiving traditional subject-oriented instruction. Statistically significant differences in understandings were found in favor of the treatment group for science, social studies, and music. The results suggest that first graders may benefit from integrated curricula.

Graves and Allen (1989, pp. 1, 5, 17, 20) compared the science and mathematics achievement of 1325 college-bound middle school students in the state of North Carolina who received integrated instruction from the UNC Mathematics and Science Education Network (MSEN) to the average achievement of the rest of the middle school students in North Carolina. The treatment included regularly scheduled classes for MSEN students, MSEN enrichment laboratory sessions, and summer enrichment. The treatment was ongoing from 1987 to 1990. In 1989, eighth graders gained an average of three grade levels in mathematics. Statistically significant gains were made on all dependent variables including mathematics and science achievement. The results suggest that long-term treatment with integrated curricula in mathematics and science including supplemental instruction may be effective in improving the achievement of college-bound students.

Dugger and Johnson (1992, pp. 20-21, 24) compared the physics achievement of 139 vocational students in an integrated technology and physics course that included an emphasis on mathematics (Principles of Technology, treatment one) to the achievement of 136 physics students (treatment two) and the achievement of 83 non-physics students (control). The integration design is what Van Til, Vars, and Lounsbury (1961, pp. 90-96) referred to as fusion; where the content of two subject areas is integrated into one course typically taught by one teacher. Principles of Technology is a curriculum "...designed to infuse general education mathematics and science concepts into the high school vocational education curriculum..." (p. 20). Principles of Technology was designed to serve average vocational students and bears many of the characteristics of technology education (McCade, 1991, p. 23). The authors stat that it fits will under the umbrella of technology education (p. 25).

After a full school year of treatment, the pretest-post test analysis revealed significant differences between the groups in favor of the Principles of Technology group over physics class and physics class over the control (Dugger & Johnson, pp. 24-25). However, the instrument used to measure achievement was designed for the Principles of Technology course. The results of this study could suggest that integrating (fusion) technology, science, and to a limited extent, mathematics may be effective as an approach for getting students to learn mathematics and science at higher levels than traditional approaches.

Scarborough and White (1994, pp. 35-37) compared the physics achievement of non-physics students enrolled in Phys-Ma-Tech (treatment, N=43) to the physics achievement of physics students (control, N=75). Like the Principles of Technology course, the Phys-Ma-Tech course is a fusion design. Intelligence quotient and grade point average were used to control for past performance and ability. The instruments were a synthesis of Phys-Ma-Tech content evaluation and national science achievement tests. There were no significant differences between the treatment and control groups, however the treatment group made significant gains during the course of each unit of treatment. The results suggest that physics and technology fusion may help students who do not usually enroll in physics learn the subject matter despite perceived ability or performance.

Ingram (1966) compared the effects of social studies integrated with an industrial arts activity (treatment) on the achievement of 250 fourth, fifth, and sixth graders to the effects of regular social studies (control) on the same students. The treatment lasted between four and six weeks. He found significant differences within groups but no evidence that the treatment affected achievement over the control method. The integrated unit "...did not prevent...significant learning in social studies." The results of the study suggest that industrial arts activities integrated as a short-term treatment may be ineffective in improving achievement.

Brusic (1991, pp. 69, 72) compared the science achievement and scientific curiosity of 58 fifth grade science students who received science instruction integrated with a technology education activity (treatment) and the same effects on 65 science students taught without the technology activity (control). The treatment was administered for an average of almost five and one-half hours over a 10 day period (p. 89). There were no significant differences between the groups in science achievement (p. 139). However, there was a significant difference in the curiosity measure in favor of the treatment group (pp. 141-142). Brusic's findings support those of Ingram and suggest that the integration of technology education activities with another subject is ineffective for improving achievement as a short-term treatment.

These 12 studies on the effects of integrated curricula are not promising. Those that found differences favoring integration tended to use large samples, long treatment periods, or treatment periods that were administered to the experimental groups longer than education was provided to control groups. Short-term treatments tended to show no significance. The TSM Integration approach used in this study is typically a relatively short-term treatment.

Summary

Reform initiatives during the 1980's, that linked economic declines with declines in student achievement, prompted recommendations for curriculum integration (Michaels, 1988, p. 3). The literature is rich with sources for a rationale for the integration of technology, science, and mathematics. These sources originate from across the education profession, but those from the respective fields themselves are especially valuable.

The Project 2061 (1989) and the National Committee for Science Education Standards and Assessment (1992) have been chief reformers in the field of science education recommending the integration of technology education, science, and mathematics curricula. Other science education reformers also recognized the benefits of including technology education in integrated curriculum arrangements (Selby, 1988; Hurd, 1991; Salinger, 1992).

The Commission on Standards for School Mathematics (1989) also contributed to a rationale for the integration of technology education, science, and mathematics. They wrote standards for, among other things, the integration of mathematics with other subjects and standards that emphasize problem solving in a manner that is somewhat similar to the approach used in technology education laboratories. Roth (1993) also recommended changes in traditional approaches to mathematics instruction, and his recommendations suggest instructional methods that would be enhanced by integration with technology education.

Leaders in the reform of industrial arts set the stage early for recent recommendations for the integration of technology education, science, and mathematics. Olson (1963) conducted pioneer work in developing a content base for industrial arts that reflected technology. This work made the connections among technology, science, and mathematics obvious. Maley (1959) was the most outstanding reformer in industrial arts and technology education to emphasize the benefits of curriculum integration. The work he did culminating in the Maryland Plan curriculum not only focussed on research and experimentation but also on the links among technology, science, and mathematics (Maley, 1967). This work underscores the influence of Maley's reform efforts with regard to curriculum integration. Lux (1984) also contributed to a rationale for technology education curriculum integration. He saw the acknowledgement of the links between technology and science as necessary for legitimate instruction and learning in technology. It was this premise that LaPorte and Sanders recognized as a major contribution of technology to science and mathematics; opportunity for application of science and mathematics principles and concepts.

Others in the field of education also contributed to a rationale for the integration of technology education, science, and mathematics. The STS movement recently recognized the value of technology education to the learning of science and social studies (Zuga, 1991). Boyer (1983) recognized the shortcomings of isolated, subject-centered science and mathematics instruction, and he emphasized the importance of technological education after he and the Carnegie Foundation reviewed American high schools. Similarly, Bruner (1977a) recognized that science and mathematics instruction was not presented in a way that best matches the structures of cognition students use for retaining and transferring knowledge to other situations. Bruner's recommendations for reform in science and mathematics were consistent with the hypothesized outcomes of integrating technology education, science, and mathematics.

The integration of curricula is not a new idea, but thanks to the revitalization of curriculum integration in the 1950's and 1960's by Van Til, Vars, and Lounsbury (1961) a variety of approaches to its implementation have been explored. Jacobs (1991a) also stands out as a leader in guiding the implementation of integrated curricula. These four leaders in middle school curriculum have suggested a variety of approaches to integration.

Perhaps the greatest value curriculum integration promises for technology education is how other school subjects and disciplines can help promote technological literacy (Zuga, 1988; Lux, 1958) and achievement in technology education (Waetgen, 1992). However, the participation of technology education teachers in assisting the understanding of concepts in other school subjects is also beneficial to the field (LaPorte & Sanders, in press).

The use of problem solving offers benefits to the learner (Bruner, 1971), and the use of problem-solving models for the guidance of teachers is a sound pedagogical practice (Bruner, 1977b; Waetgen, 1989). Technological problem solving is a part of the technological process per se and therefore, should be an important focus of research in the field (Savage &

Sterry, 1990). Real-life experience in schools, doing real technological processes, and problem solving should be blended in an integrated curriculum of technology, science, and mathematics (Dewey, 1917; Lux, 1984; Savage & Sterry, 1990; LaPorte & Sanders, in press).

With the exception of the TSM Integration Approach (LaPorte & Sanders, 1993), no models of problem solving and technological problem solving contribute to an understanding of how science and mathematics curriculum integration should be utilized within technological problem solving. While there are benefits to the solving of ill-structured problems (Hatch, 1988), not all problems in technology education or even within any ill-structured technological problem are appropriately or solely set as ill-structured. Structured problems are a realistic characteristic of technology education (LaPorte & Sanders, 1993) and the processes of technology (Shaw & Reeve, 1978).

The main concern of this researcher's study was how well science and mathematics aid technological problem solving beyond what is done without science and mathematics instruction. Therefore, identifying methods to measure the quality of solutions is important. The following list summarizes ways in which student success in problem solving and technological problem solving may be evaluated or measured.

- Collect evidence that students have been self-regulating problem solving by applying key knowledge during the evaluation of the solution (Bruner, 1966, p. 51).
- Students depend on the opportunity to compare their expectations for a solution to the actual outcomes (Bruner, 1977a, p. 20). The difference between expectations and outcomes is an indication of the success of the process.
- In solving a problem, physical representations of concepts developed by students are a measure of the concept attainment (Bruner, 1966, pp. 58-65).
- In attaining a concept, students must have the chance to observe the outcomes of changes they have made over a series of smaller problems (Bruner, p. 65).
- Among other attributes, achievement in technology education is characterized by

applying technological processes and solving technological problems (TEAC, 1989, p. 10; Bensen, 1980, p. 14).

- "...'doing' technology is the modus operandi...theory without practice is mere intellectual exercise" (LaPorte & Sanders, in press). To learn the use or value of some concept, students must try them out to experience and observe the application (Bruner, 1977a, pp. 29-30). To confirm theory one must apply it, test, and observe the application.
- In science, the quality of conclusions students make about an experiment are measured by the evidence they gather. This evidence is often directly observed or measured with an apparatus (Project 2061, 1989, pp. 147-149). Technological problem solving is similar, and as a process of technology it has as its goal the satisfaction of wants and needs (Savage & Sterry, 1990, p. 12). The systematic application of technological processes provides feedback (Does the technology do what

it is supposed to do?), and the context in which the technology is needed is the setting for testing the extent to which it satisfies the need (pp. 13, 15, 18).

- Simulations, models, and working models may be used to represent outcomes of technological processes (Tracey, 1990, pp. 138-143).
- Technical apparati may be used to collect data about a problem (Johnson, 1994, pp. 27-28).
- The extent to which subjects are able to change hypotheses based on what they observe can be measured over a series of events in which subjects try to arrive at a solution (Bruner, Goodnow, & Austin, 1956, pp. 128-131)
- Given the opportunity to solve a problem in iterations, the subject can be evaluated by the extent to which attributes of the solution are changed during the iterations (p. 140).
- The degree to which a solution is correct may be an indication of the degree to which the student proved each step in the process or performed trouble shooting (Polya, 1948, p. 12).

- Solutions may be developed in different ways so long as they arrive at the correct answer (Polya, p. 14). In technological problem solving, this is similar to satisfying an objective or some want or need.
- If convergent thought processes are required to bring a solution into implementation (Shaw & Reeve, 1978, p. 7), then the very existence of a solution is a measure of the existence of the thought processes. The quality of the total solution must be the extent to which it satisfies a criterion, objective, need, or prediction.
- Collect evidence that the solutions have been systematically changed (Maley, 1992, p. 6).
- The instructional unit may provide a criterion reference against which solutions may be compared, as is done in the TSM Integration Activity, "Capture the Wind" (Sanders, 1993, p. 58).
- If the instructional unit provides structure or constraints within which students must solve the problem, as is the case with TSM

Integration Activities (LaPorte & Sanders, 1993, p. 18), then whether or not students stayed within the structure could be a measure of problem-solving success.

- If the instructional unit provides a method or procedure by which solutions are judged, as is the case in TSM Integration Activities (Sanders, 1993, p. 59), then the procedure may provide an indication as to the ability of problem solving.
- Mathematics may be used to determine the effectiveness of problem solutions (LaPorte & Sanders, 1992, p. 2).
- Observing the behavior of a technological solution may be used to assess some quality of some attribute of the solution. For example a boat travels slowly because it sits deep in the water (p. 4).
- The differences in problem solutions can be judged by comparing solutions to each other. For example, one can see if one boat goes faster than another (p. 4).
- Gather evidence that indicates the extent to

which students applied theory to guide their solution process (Lux, 1984, p. 18; LaPorte & Sanders, 1992, p. 10).

- A direct technique for evaluating student processes is asking the student why certain things are occurring (Haury & Rillero, 1992, pp. 13-15).

Student evaluation and assessment in problem-solving tasks is typically subjective, but in technology education it seems to be authentic in that students are evaluated for performance that is important in technological fields and practice. The TSM Integration Project is a pioneer technology integration effort that uses the application of science and mathematics principles and concepts to assist in the solution of technological problems. Observations of the effects of such an approach are important targets of research in technology education curricula.

Unfortunately, only sparse research results are available from studies on curriculum integration in general. The vast majority of the studies reviewed were conducted as pretest-posttest control group designs using analysis of variance. The general trend of these studies, some being more relevant than others, is that long-term treatments of integrated curricula and/or instruction seem more likely to improve student achievement. Short-term treatments do not tend to yield significance. Furthermore, the majority of the studies reviewed herein were doctoral dissertations, and a majority found no significance. This suggests that funded long-term treatments of integrated curricula should be studied under the control and expertise of professional educational researchers.

Chapter Three

Methodology

Design of the Study

A quasi-experimental, non-equivalent control group design was employed to measure the effects of correlated technology education, science, and mathematics curriculum integration upon the technological problem-solving ability of technology education students (Cook & Campbell, 1979, p. 6; Pedhazur & Schmelkin, 1991, p. 278). See Figure 3.1 below. This design was required because the circumstances present in the schools prohibited experimental designs and other quasi-experimental designs (Campbell & Stanley, 1963, p. 47).

	pretest after first iteration		posttest after second iteration
	O	**X**	**O**
	O		**O**
first iteration of problem solving with no treatment		treatment in second iteration of problem solving	

Figure 3.1
The Research Design

Hypothesis. The following hypothesis was posed as the basis of the study. It is predicated on the research questions stated previously and on the literature review. The null form of the hypothesis is presented first.

Ho: There is no significant difference between the technological problem-solving ability of technology education students receiving correlated instruction in science and mathematics (treatment group) and the technological problem-solving ability of technology education students who do not receive correlated instruction (control group).

Ha: The technological problem-solving ability of students participating in the curriculum integration group (treatment group) will be superior to that of students not in the integration group (control group).

Since the literature and the logic of the experiment support the notion that the experimental group would out perform the control group, a one-tailed test was used. Because the hypothesis is based on the effects of technology, science, and mathematics integration on technological problem solving, technological problem-solving ability will be measured.

Treatment. The students were to design, construct, and evaluate a wind collector to convert wind energy into electrical energy. The collectors were mounted on a generator; the generator was held constant from pretest to posttest. The measures for treatment effects (or the performance of the wind collectors) were the amperage output and the voltage output of the generator.

Sample. The samples for the pilot study and the experimental study are summarized in Table 3.1. Several requirements delimited the sampling frame for this study and its pilot study. Due to time constraints, the samples were drawn as a matter of convenience within the structure of sampling frame requirements. Because of costs, the sampling frame was delimited to middle schools in Virginia. Because of the quasi-experimental design and an experimental attempt to control confounding variables, the samples were drawn from middle schools that had two or more technology education teachers in the same school. Each teacher had to have access to a general technology education laboratory, and each had to teach classes at the same grade level.

Additionally, because the feedback from the TSM Integration Project suggested that implementing curriculum integration is difficult and requires commitment from the teachers involved (Sanders, 1993, p. 59; LaPorte & Sanders, 1992, p. 5), the sampling frame was composed of schools that had demonstrated an interest in curriculum integration.

Having obtained permission from the administration, the sample in the pilot study was selected from a middle school in a rural area of south-central Virginia. The treatment group technology education teacher for the pilot study was part of a team that participated in a workshop on curriculum integration co-sponsored by the TSM Integration Project. Originally, the researcher proposed a factorial design to investigate the effects of being female or African American, but there were insufficient numbers of subjects to conduct a meaningful analysis. One class of eighth grade technology education students was available to act as the treatment group, and it consisted of 16 students, including three females and four African Americans.

The pilot study control group teacher had two classes of eighth grade technology education students. It contained 35 students total, with three females and 15 African Americans.

It is important to note that because the science and mathematics concepts taught in the treatment did not coincide with the current scheduling of the regular science and mathematics curriculum, the willing treatment teachers had to teach the science and mathematics in the technology lab during their common planning periods. This constraint determined which class of students under the treatment teacher would be selected. The experimental design and the constraints to TSM curriculum correlation limited the sample size.

The study sample was selected from a middle school in a suburb of Richmond, Virginia that had participated in a "Making the Connections" workshop on curriculum integration during the previous school year. Two of the technology teachers taught eighth grade classes and had general technology education laboratories that were required for the construction of the technological solutions. They agreed to participate in the study after the administration at the study site approved it.

The technology teachers recruited the science and mathematics teachers for the study. Because the science and mathematics concepts taught in the treatment did not coincide with the current scheduling of the regular science and mathematics curriculum, the willing treatment teachers had to teach the science and mathematics in the technology lab during their planning period. It is important to note that the technology teacher that would participate in the treatment was assigned on the basis that he taught eighth graders during the planning period of the science and mathematics team members. This limited the sample size. The control group teacher had his planning period during the treatment class period. The existence of such constraints to TSM curriculum integration are consistent with the literature (Bergman, 1992, p. 189; George, 1982, p.12; LaPorte & Sanders, 1993, p. 19; Merenbloom, 1981, pp. 1-2; Salinger, 1992, p. 45).

Though he had all eighth grade classes, only one class was selected for the control condition. This control group was selected based on anticipated interruptions to the instructional schedule. The control group would need to experience the same interruptions as the treatment group. Other classes taught by the control teacher were not going to experience the same interruptions.

Table 3.1
Delineation of Samples

	Treatment	**Control**
Pilot Study	16	35
Females	3	3
Minority	4	15
Experiment	17	16
Females	2	0
Minority	3	5

The study treatment group consisted of 17 students, three of whom were female and three African Americans. The control group had similar enrollment but no female students. The treatment and control group numbers are shown in Table 3.1.

Apparatus to measure treatment effect. The measures for treatment effects (or the performance of the wind collectors) were the amperage output and the voltage output. To sample voltage and amperage, the wind collector solution was mounted onto the shaft of the generator. The generator, fan, distance from the fan, multimeters, and sampling time were held constant for every reading throughout the study.

Each wind collector was given 30 seconds to get up to speed. The highest readings in that period were recorded. These values were multiplied to calculate the power output of each solution.

The generator was connected in a parallel circuit with a power resistor serving as a load for the circuit. The power resistor was of a rating that provided full load for the circuit. The ammeter was connected in series with the circuit, and the voltmeter was connected in parallel across the load.

Modern multimeters, voltmeters, and galvanometers or ammeters are statistically reliable measurement instruments. The likelihood of random error is small. A malfunction of the device would have to occur. Because the multimeter is used to take measurements from mechanisms, random error is again less likely. Most machines typically do not widely vary in their performance. Systematic error was possible in collecting these data during the pilot study, however, the training of all technology teachers in the proper use of multimeters minimized this threat (Pedhazur & Schmelkin, 1991, pp. 225-227). Systematic error was much less likely at the study site because the researcher administered the pretest and posttest.

The variations of pilot study pretest voltages, pilot study posttest voltages, and sample generator voltage were compared using a t-test analysis. The sample generator analysis was conducted *a priori*. The comparison of the three voltage outputs was conducted *ex post facto* for the pilot study. The pilot study power readings were taken in a manner consistent with the testing procedure described above. The sample generator readings used one collector (constant) during a two and one-half hour period. See Table 3.2.

Any variation in the output of the sample generator over the two and one-half hour period was significantly smaller than the variation of student-made wind collector output. In qualitative terms, the variation of the sample generator output was minute.

Table 3.2
T-Test For Generator Variation

Dependent Variable: Generator Voltage

Group	Count	Mean	Std.Error	95% Conf.		Prob > T
Pretest	16	127.5	8.62	109.0	145.8	0.0000•
Generatr	16	411.1	0.99	409.0	413.3	

Group	Count	Mean	Std.Error	95% Conf.		Prob > T
Posttest	15	216.9	23.91	165.6	268.2	0.0000•
Generatr	16	411.1	0.99	409.0	413.3	

The life of the sample generator was determined to be constant during the two and one-half hour period. The generator was operated constantly during this period and its output was sampled every five minutes. Figure 3.2 (not available) shows an overlay plot of the variation in sample generator output voltage, average student pretest voltage for the pilot study treatment group, average student posttest voltage for the pilot study treatment group, and the absolute time interval during which the generator would be used for measuring student power output. It is during this interval that the generator is extremely reliable. The break-in time for the generator was 15 minutes. The most reliable output begins after 15 minutes of continuous operation until 100 minutes of continuous operation. See Figure 3.2.

As a result of the life span analysis, all practice generators, the pretest-posttest generators, and the pretest-posttest back-up generators were operated for 15 minutes before being used in the pilot study and the study. Each teacher was instructed to discard practice generators after 40 service minutes of operation.

Internal validity. Although true random sampling could not be employed, several considerations were made to minimize threats to internal validity. Krutchkoff (1993) suggested that the sampling of subjects in the study could be though of as random provided students were assigned to classes for no particular reasons and no significant differences in technological problem solving ability exist at the pretest. His reasoning was that all of the available population

(Not Available)

Figure 3.2
Generator Voltage Change Versus Average Student Voltage Change and Generator Break-In/Service Life

meeting criteria for selection were selected and that the intact groups were not originally formed due to some biased reason. For example, the technology education classes were not formed because all of the students in a particular class were gifted or of a particular race.

To maximize internal validity, the treatment and control groups were contained within the same schools.

All of the technology teachers were experienced at teaching technological problem solving, and all of the technology students that would experience the same extraneous conditions and interruptions were used for the study.

Given this approximation, if the difference in pretest and posttest means is greater for the treatment group, then the quasi-experimental, nonequivalent control group design would have controlled for the effects of history, maturation, testing, and instrumentation because the main effects of these confounding variables should have affected both groups equally (Campbell & Stanley, 1963, p.48).

In addition to the control provided by the pretesting and the presence of the control group, certain other aspects of the experiment helped to maximize internal validity.

History was controlled insofar as the teachers followed the adapted TSM Integration materials, but this does not control intrasession history.

Maturation is minimized by this design. Take, for example, the effects of students becoming hungry near the end of the school day or before lunch. The presence of the control group minimizes this threat because all students will likely become hungry (p. 48).

Testing was minimized as a threat by the fact that the measures of technological problem-solving ability were simple behavioral objectives or what could be considered design criteria. These measurements were taken only twice. See Figure 3.1.

Instrumentation was not a threat to internal validity. No instrument was used in the sense that students took written formal tests. Data were obtained through the direct physical measurement of the technological solutions built by students.

Imitation of treatment and treatment diffusion were controlled insofar as the teachers followed the adapted TSM Integration materials (Pedhazur & Schmelkin, 1991, p. 228).

There was no mortality in the study.

The effects of selection and regression toward the mean (RTM) could have threatened internal validity because they were not as well controlled (Campbell & Stanley, 1963, p. 48). Preexisting differences in the groups would be suspected upon a significant between-group pretest resulting after the first iteration of technological problem solving. On the other hand, no significant differences between groups on the pretest would suggest that preexisting differences were not going to affect the study if differences did actually exist.

RTM would be expected in that students who did real well on the pretest would not be expected to do as well on the posttest. However, the groups were not formed based on high achievement or giftedness, etc. (p. 49).

External validity. While the researcher may be able to make generalizations about the effects of technology, science, and mathematics integration on the technological problem-solving ability of the future eighth graders at the school for the study, he would not be able to generalize about just any school. However, Krutchkoff (1993) maintained that insofar as the sample is essentially random (no significant pretest differences between groups), the results are generalizable to schools that take an interest in technology, science, and mathematics curriculum integration.

Even studies employing probability sampling may lose their true external validity through attrition.

Inability to generalize across populations is not uncommon in field-based research. Cook and Campbell (1979) stated, "A case can be made, therefore, that external validity is enhanced more by a number of haphazard samples than by a single study with initially representative samples..." (p. 73). They stated that typical practice in field-based research "is more one of generalizing across haphazard instances where similar-appearing treatments are implemented" (p. 73).

Yet, external validity should not be applied without caution. For example, a well-meaning school principal could not generalize these results to all teachers, volunteer or not, technology teachers or not. Given this study and the others cited in the review, treatment must be administered to many different populations to generalize across them (p. 74). To generalize the effects of the treatment in different circumstances, the treatment must be administered under different circumstances.

Analysis of Variance. A three-way analysis of variance on treatment, race, gender, treatment-race, and treatment-gender interactions was proposed to test the hypothesis in this study. However, it was dropped after the pilot study data (see Pilot study, Chapter Three) and the sample sizes related to race and gender within the study (see Sample, Chapter Three) were determined to provide insufficient power for the analyses (see also, Pilot study). Many studies related to aspects of this study considered race and gender in the design of the experiments and the data analysis (Ballard, 1982; Brunk & Denton, 1983; Clayton, 1989; Glasson, 1989; Graves & Allen, 1989; Graw, 1981; Scanlin, 1985;).

T-test analyses. T-tests were employed *ex post facto* to determine the relationships between the groups on certain solution attribute variables. These are variables that designate features of the wind collector designs such as the materials used, the pitch angles of the blades, etc.

All of the statistical analyses were generated by the researcher with the *Number Cruncher Statistical System*, a computer program.

Qualitative analysis. A qualitative method of research was employed to collect information that could not be collected by pretest and posttest measures (Glasson, 1993). Although the main focus of this study was to determine whether technological problem solving is improved by the integration of science and mathematics, technological problem solving was in a certain sense, used in this study as an indicator of the student's ability to apply science and mathematics concepts to the design, construction, and evaluation of technological solutions. This is a difficult construct to measure. The performance of a device, or to a certain extent the students themselves, will not allow the researcher to understand what is going on inside the students' minds. Qualitative methods take the researcher closer to what the subject is thinking. "Without a qualitative understanding of how culture mediates human action, we can know only what the numbers tell us...it can help us to situate these numbers in their fuller social and cultural context" (McCracken, 1988, p. 9).

Interviews were used to measure the extent to which students were consciously applying science and mathematics. The same interviews were conducted with both treatment and control group students. The interviews were tape recorded with each student's permission.

The purpose was to further the understanding of the unmeasurable constructs believed to be operating in the study. In-depth interviews were conducted with six students in each group selected by the researcher during the pilot study. The 12 total students interviewed at the study site were drawn randomly.

Questions were composed to better insure consistency in the focus of students' responses to the inquiry about their applications of science and mathematics. The questions were designed to see if the student is applying the science and mathematics principles in Topics I and II of the science and mathematics sections in the "Capture the Wind" activity materials.

The questions did not directly mention those principles and concepts so as to avoid biasing the procedure. They were phrased in such a way that it is impossible to give one word responses such as yes or no. If the student gave a short response, the researcher would prompt him or her for more information without being suggestive. For example, if the student answered question one below, "Because I changed its blades," then the researcher would respond, "Changed its blades?"

1. *Why do you think that your wind collector will*

generate more power this time compared to what it generated last time?

Possible Responses:

1a. The student could tell the researcher all about the integration of concepts the science and mathematics teachers taught.

1b. The student could respond by describing the way in which a particular change was made.

1c. The student could describe an idea or principle that was applied to the improvement of the solution.

If the student did not mention the instruction received in science or mathematics but was rather elaborative about the change/changes he or she made to the solution, then the researcher asked question 2.

2. *How did you learn of this new strategy/concept/approach?*

If the student was rather elaborative about generally using science and mathematics in the improvement process but did not mention much about the actual concepts, then the researcher asked question 3.

3. *What did you learn that gave you this idea?*

After seeking some response from the student that referenced the science and mathematics instruction and content, the researcher asked the remaining questions if the student did not answer them during responses to the preceding questions.

- Why are the blades on your wind collector bent at an angle?

- Why did you use X number of blades on your wind collector?

- How do you know that your wind collector is not larger than 122 cubic inches/2000 cubic centimeters?

- If you made more than one change to your wind collector, how can you tell which change made it improve/get worse?

Adaptation of "Capture the Wind." See Appendix A. The researcher decided to only include Topics I and II of the science and mathematics resource sections of the "Capture the Wind" activity because they were the only topics included in the materials upon which the improvement of solutions should depend. Other topics in these resource sections were characterized as "nice to know" content.

Topic I of the science section provided content about how the force of wind could be redirected by the wind collector solutions. It involved a qualitative demonstration. Topic II of the science section provided content on experimenting to identify the optimal pitch angle of wind collector blades. Topic I of the mathematics section provided content on how to calculate the maximum volume of the wind collectors. Topic II of the mathematics section provided content on how to chart and graph relationships between the pitch angle or number of blades and wind collector output.

The technology sections for the treatment and control group technology teachers were identical except that the control version contained no references to science and mathematics teacher planning or correlation. The content of the technology section provided:

- Knowledge of how generators work.
- Knowledge of how student solutions would be mounted and tested.
- Historical information on wind power.
- Advice on considering how to maximize the size, what materials to consider, what to do with dead space such as the hub area, whether to maximize or minimize the mass, and how to keep the wind collectors rigid.
- Information on how to administer the pretest, posttest, and first and second iterations of problem solving.

After the pilot study, the treatment and control versions of "Capture the Wind" were reexamined and ambiguities were corrected. The instructions for the technology resource section in the unit were simplified. All non-essential components of the "Capture the Wind" activity materials were eliminated.

The Pilot Study

A pilot study was conducted to determine the feasibility of the study and determine if aspects of it needed revision (Ary, Jacobs, & Razavieh, 1985, p. 87). The following describes the pilot study, pilot study findings, and revisions to the study.

First iteration. The pilot study proceeded as follows. After permission was obtained through the administration, training for the pilot study teachers was conducted by the researcher at the school on February 18 and again on March 1. The first iteration of technological problem solving (design, construct, and evaluate a wind collector) required two weeks for the pilot study treatment group and three weeks for the control group. During this period, both the control and treatment group students received the same treatment. This treatment involved no curriculum integration and was prescribed in the adapted TSM Integration unit entitled "Capture the Wind." See Appendix A for the revised version of "Capture the Wind."

Within the first iteration, the students were presented with the problem to solve, they designed solutions, and they constructed the solutions. They were provided with the testing apparatus and a generator that was used for students to intermittently test their solutions while they were still working on them.

On April 11, the pilot study treatment group teacher collected pretest measures. During the pretesting, the treatment group teacher realized that the solutions were all too small because of ambiguity in the "Capture the Wind" design brief. Under the intended design constraints of the unit, the wind collectors could be made much larger than they were. Additionally, the pilot study science and mathematics teachers were unable to begin the treatment following the pretest because they had to conduct teacher-parent conferences during their interdisciplinary-team planning period. This was the planning period dedicated to the treatment. In light of these developments, the decision was made to redesign and reconstruct treatment group solutions. The pilot study control group teacher did not misinterpret the size constraint requirement of the "Capture the Wind" design brief. The control group was ready to pretest two days after the treatment group began to correct the sizes of their solutions.

Since the times for the groups to work were not equal, the researcher decided that no matter what, the time allowed for the first iteration of problem solving would be the same for both groups at the study site. The amount of time students would be allowed for lab work in the second iteration would be the same for both groups also.

The science and mathematics teachers at the study site made a commitment to not allow conflicts to interfere with the administration of the treatment so that avoidable delays like those in the pilot study could be avoided.

Pilot study control group pretest. All of the pilot study control group student wind collectors were under the maximum size of 122 cubic inches and did not change appreciably from pretest to posttest.

The number of unmeasurable wattage observations and missing observations from the control group pretest alerted the researcher that student progress may not have been monitored. The number of unmeasurable scores actually makes even analyses like the Kruskal-Wallis, a nonparametric analog of ANOVA, or any analysis unrealistic.

The pilot study control group included 35 students.

On the pretest, 17 student solutions generated unmeasurable milliwatts of electrical power. Of the 35 students, 9 were responsible for missing observations because they were absent on the pretest day. The decision was made that in the study, wind collectors were not to be stored in the students' laboratory lockers or hall lockers. Instead, they were to be stored in the respective study teachers' offices at the end of each class period. This ensured that the solutions would be available for testing even if any students who constructed them were absent on the test day.

Based on these findings, it was decided that the study teachers needed to be trained to monitor student progress so that the iterations of problem solving would not end with unusable data.

Furthermore, the researcher decided to have the treatment and control technology teachers for the study observe each others' lectures and demonstrations but not lab work instruction during the first iteration of problem solving prior to the pretest to ensure they taught in exactly the same ways. After the pretest, they did not observe each other.

Circumstances in pilot study treatment group

pretest and posttest. The pilot study treatment group required eight additional days from the day the ambiguous size constraint was discovered to correct their solutions. The control group teacher was instructed to proceed with the second iteration of the pilot study problem solving. Students were to improve power output. They could rebuild or make changes to their existing solutions. Most opted for the latter.

The day after the corrected treatment group pretest, the treatment was administered. The mathematics teacher taught Topics I and II of the "Capture the Wind" mathematics resource over three class periods. The science teacher taught Topics I and II of the science resource during one class period. The treatment science and mathematics teachers taught the treatment groups in the technology lab, but neither they nor the technology education teacher team-taught the concepts. Five class periods of lab work were required for the treatment students to improve their solutions. After four days of improvement lab work, the control group teacher administered the posttest. The treatment group teacher damaged the test generator after the control group teacher administered the posttest but before administering the treatment group posttest.

Based on the damaged generator, the researcher decided the pretest and posttest for the study would be administered by himself and that he would keep the single generator used in the testing. This would ensure that the test generator would not get damaged during the study.

Pilot study control group posttest. On May 4, the researcher collected pilot study control group pretest and posttest data and conducted interviews with the control and treatment students. Based on the number of missing observations and unmeasurable wattage readings on the control group pretest and posttest no analysis could be done that included the control group data. In light of this, the researcher decided that the posttest for the pilot study treatment group was to be personally supervised.

Additionally, the study also would be closely supervised by the researcher with a total of four days supervised during the beginning and one day near the end of the first iteration of problem solving. The treatment iteration of the problem solving would be supervised for one day.

Pilot study treatment group posttest. The posttest data were collected from the pilot study treatment group and used in an analysis against the treatment group pretest.

The pilot study treatment group pretest/posttest analysis of variance for wattage suggested that technology education, science, and mathematics curriculum integration may significantly improve the technological problem-solving ability of technology education students for the particular TSM Integration Activity. The reliability of this finding was questionable because a different generator had to be used in the posttest than was used in the pretest. However, both generators had the same specifications. See Table 3.3.

The pilot study treatment group pretest/posttest analysis of variance for volume change suggested that the treatment of technology education and mathematics curriculum integration may not significantly improve the ability of students to maximize the sizes of the wind collectors, but the mean increase suggested that they were attempting to apply mathematics.

Table 3.3
Analysis of Variance for Treatment Group Pretest

and Posttest Wattage

Source	DF	Sum-Squares	F-Ratio	Prob>F
Wattage	1	109.7	9.62	0.0054•
Error	21	239.7		
Total	22	349.5		

Term	Count	Mean	Std. Error
All	23	3.898	
A: Wattage			
Pretest	10	1.695	1.068
Posttest	13	6.102	.9371

Pretest missing values due to solutions exceeding the size limits. One missing value in posttest due to absence.

The treatment group included 16 students none of whose collectors generated unmeasurable milliwatts and none of whom were responsible for missing observations on the pretest due to absences, etc. Six students were over the size limit at the pretest, and five of them corrected the sizes of solutions before the posttest. In changing the volumes, these five students tended to over compensate.

Pilot study interviews. The results of the student interviews are listed in Table 3.4 for the treatment and control groups respectively. The responses are based on why the student believed that he or she would design a better solution in the second iteration of problem solving compared to the one made in the first iteration of problem solving. The pilot study interviews were conducted after the treatment instruction but before the end of the second iteration of problem solving.

There appears to be evidence that treatment group students connected improving their solutions with the science and mathematics concepts. The fact that they also mentioned specific science and mathematics concepts may provide further evidence that they were able to apply science and mathematics to their technological solutions. They also appear to be able to apply science and mathematics by evidence of their ability to control a solution attribute variable such as pitch angle.

Table 3.4
Categorized Responses of Interviewed Students to Why They Felt Their Second Solution Would Perform Better Than the First (n=6)

No.	**Reason (Treatment)**
5	Based on what I learned through math and science instruction (general).
4	Pitch angle experiments in science
4	Control a variable in an experiment
4	Determine the way to maximize volume
1	Based on what I learned from observing other

No.	Reason
	students.
3	Intuition based on what I learned from building the first wind collector.

No.	Reason (control)
1	Based on what I learned through technology instruction (general design considerations).
4	Pitch angle
0	Control a design variable
0	How to maximize volume
1	Based on what I learned from observing other students.
5	Intuition based on what I learned from building the first wind collector.

There appears to be no evidence that control students understood how to control attribute variables correctly in order to improve solutions. There was no evidence identified that copying ideas was prevalent. There is also little evidence that students associated their ideas for improvement in the second iteration with the technology education instruction. As a result, the technology teachers at the study site were trained how to monitor student progress.

Conducting the Study

The study teachers were explicitly told about the results and findings of the pilot study and were trained to avoid repeating similar errors. The guidance counselor at the study site was asked if the students were assigned to classes for any particular reasons. He indicated that there were no particular reasons for the assignments.

The first iteration of problem solving and technology education instruction for both the treatment and control groups began on the same day. No treatment was administered during this period. The first iteration lasted 15 days. The pretest was administered on day 16 to both groups. No significant differences were found between the two groups. See Chapter Four, Findings.

Treatment began for both groups on day 17 after the pretest. The treatment group received one and one-half class periods of science instruction and activity and one class period of mathematics instruction and activity. The control group received no science and mathematics instruction. Based on the pilot study, the control group proceeded with the improvement of the solutions over five class periods. The treatment group received the same amount of lab work time to improve their solutions. Student interviews were conducted two days after the treatment began. The posttest was administered to both groups after the treatment group completed their solution improvements, but both groups had the same amount of lab time in which to work on their collectors.

Time Line of the Study

The pilot study began on March 21, 1994. It took approximately six and one-half weeks to complete. The data were analyzed between May 4 and May 10. First, control group data became available followed by treatment group data on May 10. Necessary changes were made to the design and materials, and the study began on May 11 at the study site. After approximately five weeks, the site-based portion of the study concluded and the analyses of the data were conducted. See Figure 3.3.

End Pilot Study		Begin Study		Report Findings
.—May10 —	**May4 - 10 —**	**May 11 —**	**June 14 —**	**July 11—**
	Analyze Pilot Study & Make Changes		Analyze Study	

Figure 3.3
Time Line of the Study

Summary

This study used analyses of variance, t-tests, and qualitative interviews to observe the effects of technology education, science, and mathematics curriculum integration on the technological problem-solving ability of technology education students. The non-equivalent control group quasi-experimental design was used to control for the effects of confounding variables as much as possible. It was hypothesized that the technological problem-solving ability of the treatment group would significantly exceed that of the control group. The reliability of the measurement instruments was regarded as high by the researcher. A pilot study was conducted prior to the study to determine the revisions that would be needed to the conduct of the study.

Chapter Four

Findings

Introduction

The purpose of this study was to investigate the effects of technology education, science, and mathematics curriculum integration on the technological problem-solving ability of eighth grade technology education students. The researcher compared the performance of students receiving correlated science and mathematics integration to those not receiving integration in an adapted TSM Integration Activity (LaPorte & Sanders, in press). This chapter reports the findings of the study.

Pretest Analysis

Students in both the experimental group and the control group were required to design, construct, and evaluate a collector to generate electricity from the wind, as specified in a Brief adapted from the "Capture the Wind" activity from the TSM Integration Project (LaPorte & Sanders, in press). No correlated science or mathematics instruction was provided to either group in the first iteration of problem solving. The technology teachers for the two groups taught with the same materials and in the same way during this iteration. It is important to note that both groups had the same amount of time to physically build their wind collectors in the labs. The pretest measure was the output wattage (power) produced by the students' solutions to the problem specified in the Brief.

Pretest results. Using analysis of variance, no significant difference was found between the treatment and control group in performance on the pretest. Thus, the treatment and control groups were not considered to have significantly different problem-solving ability prior to the administration of treatment for the particular TSM Integration Activity. The analysis is reported in Table 4.1.

Table 4.1
Pretest Analysis of Variance for Milliwatts Generated

Source	DF	Sum-Squares	F-Ratio	Prob>F
Group	1	33.5	0.18	0.6708
Error	31	9336.1		
Total	32	9369.7		

Term	Count	Mean	Std. Error

A: Group			
1 control	16	25.06	4.33
2 treatment	17	27.08	4.20
alpha = .05			

Posttest Analysis

Analysis of variance was employed to test the following hypothesis.

Ho: There is no significant difference between the technological problem-solving ability of technology education students receiving correlated instruction with science and mathematics (treatment group) and the technological problem-solving ability of technology education students who do not receive correlated instruction (control group).

Stated as a research hypothesis:

Ha: The technological problem-solving ability of students participating in the curriculum integration group (treatment group) will be superior to that of students not in the integration group (control group).

Since the literature and the logic of the experiment support the notion that the experimental group would out perform the control group, a one-tailed test was used.

Table 4.2
Posttest Analysis of Variance for Milliwatts

Source	DF	Sum-Squares	F-Ratio	Prob>F
Group	1	350.1	1.45	0.2374
Error	31	7476.9		
Total	32	7827.0		

Term Error	Count	Mean	Std.
A: Group			
1 Control	16	36.71	3.88
2 Treatment	17	30.19	3.76

alpha = .05

In the second iteration of problem solving after the pretest, the students in the experimental group were provided with science and mathematics instruction correlated directly to the wind collector problem (treatment condition). The students in the control group received no correlated instruction (control condition). Once again, both groups were instructed to design and build a second wind collector or make improvements to their original collectors. According to the technology teachers, most students opted to make improvements to their original collectors. Both the treatment group and the control group were given the same amount of time in lab to physically implement improvements to their collectors. The output power was then measured, and the two groups were compared.

Posttest results. Using analysis of variance, no significant difference between the experimental and control group was found. Therefore, the researcher failed to reject the null hypothesis. These data are reported in Table 4.2. It is important to note, however, that both groups improved.

Although both groups improved, the mean power produced by the students' solutions favored the treatment group in the pretest and the control group in the posttest. Again, neither of these differences were found to be significant.

Additionally, in inspection of the data, eight increases and 7 decreases in wattage output were found for the treatment group which had an overall gain. However, all but two solutions for the control group performed better on the posttest. Why did more treatment students perform lower on the second iteration than on the first? Also, why did the mean of the control group go from being less in the pretest to higher in the posttest? To answer these questions and explain the results, the researcher employed t-test analyses.

T-Test Analyses

The inspection of data showed a trend in the control group posttest solutions, 14 of the 16 solutions were made from metal compared to only 8 made of metal at the pretest. Furthermore, the control group students who changed to using collectors made of metal at the posttest, first made solutions that performed significantly lower at the pretest as shown in Table 4.3. Finally, there was no difference in the power output of these solutions compared to the others at the posttest.

Table 4.3
T-Test For Control Group Solutions at the Pretest, that Later Switched to Metal

Dependent Variable: Wattage

Group	Count	Mean	Std.Error	95% Conf.		Prob > T
Change	6	11.58	5.23	-1.82	24.99	0.0072•
No Change	27	29.33	3.15	22.83	35.82	

The adapted TSM Integration Brief stipulated that the wind collectors could not be over 122 cubic inches in size. The mathematics instruction was correlated with the Brief in order for treatment students to maximize the size of their wind collectors. The significant difference in collector size in favor of the treatment group is shown in Table 4.4. Additionally, the treatment group had not fully maximized the sizes of their wind collectors.

Table 4.4
T-Test For Size Constraint

Dependent Variable: Collector Size in Cubic Inches

Group	Count	Mean	Std.Error	95% Conf.		Prob > T
Control	16	62.75	6.64	48.59	76.91	0.0155•
Treatment	17	83.46	6.31	69.99	96.92	

During the second iteration for treatment group students, the adapted TSM Integration Activity correlated science instruction related to the pitch angle of the collector blades. This science instruction included an experiment in which students varied the pitch angle of Tinker Toy-like wind collectors. According to the science teacher, students concluded that 15 degrees was the best pitch angle to try on their wind collectors. Table 4.5 shows the large frequency of students using lower degrees of pitch angle after the science instruction.

Table 4.5
Number of Treatment Group Wind Collectors Using Low Pitch Angle

15 degree pitch angle:	10 students
Other pitch angle:	7 students
20 degrees or less:	15 students
Greater than 20 degrees:	2 students

Student Interviews

The results of the student interviews are listed in Table 4.6 for the treatment and control groups respectively. The responses are based on why the student believed that he or she would design a better solution in the second iteration of problem solving compared to the one made in the first iteration of problem solving. The only opportunity the researcher had to conduct the interviews was after the administration of the science treatment but before the administration of mathematics treatment. Unlike the pilot study interviews, the study interviews omitted questions about maximizing the size of the collectors.

Table 4.6
Categorized Responses of Interviewed Students to Why They Felt Their Second Solution Would Perform Better Than the First (n=6)

No.	Reason (Treatment)
4	Based on what I learned through math and science instruction (general).
4	Pitch angle experiments in science
3	Control a variable in an experiment
1	Based on what I learned from observing other students.
2	Intuition based on what I learned from building the first wind collector.
No.	**Reason (control)**
3	Based on what I learned through technology instruction (general design considerations).
2	Pitch angle
2	Control a design variable
2	Based on what I learned from observing other students.
3	Intuition based on what I learned from building the first wind collector.

Summary

The pretest of technological problem-solving ability showed no significant difference in the treatment and control groups prior to the administration of treatment. This suggested that there were no significant differences in problem-solving ability between the groups prior to the administration of treatment for the particular TSM Integration Activity.

The test of the hypothesis showed no significant differences between the treatment and control groups in wattage output at the posttest.

T-tests showed that control students who performed significantly the lowest on the pretest coincided with not using metal in the wind collectors constructed in the first iteration of problem solving. All other students in the group used metal in the first iteration. Of these same students, those who switched to metal in the second iteration of problem solving showed no significant difference from other students.

A t-test showed a significant difference in the size of wind collectors between the groups in favor of the treatment group. However, sizes of the treatment group collectors were not fully maximized.

Finally, the results of the student interviews were summarized.

Chapter Five

Summary, Conclusions and Recommendations

Summary of the Study

The purpose of this study was to investigate the effects of technology education, science, and mathematics curriculum integration on the technological problem-solving ability of eighth grade technology education students. The researcher compared the performance of students receiving correlated science and mathematics instruction to those not receiving correlated instruction in an adapted TSM Integration Activity (LaPorte & Sanders, in press). This chapter reports the conclusions and recommendations of the study.

Students in both the experimental group and the control group were required to design, construct, and evaluate a collector to generate electricity from the wind, as specified in a Brief adapted from the "Capture the Wind" activity from the TSM Integration Project (LaPorte & Sanders, in press). No correlated science or mathematics instruction was provided to either group in the first iteration of problem solving. The technology teachers for the two groups taught with the same materials and in the same way during this iteration. Both groups had the same amount of time to physically build their wind collectors in the labs.

The pretest measure was the output power (wattage) produced by the students' solutions to the problem after the first iteration as specified in the Brief. Using analysis of variance, no significant difference was found between the treatment and control group in performance on the pretest. Thus, there were likely no significant differences in the problem-solving ability of the two groups prior to the administration of treatment for this particular TSM Integration Activity.

In the second iteration of problem solving that occurred after the pretest, the students in the experimental group were provided with science and mathematics instruction correlated directly to the wind collector problem (treatment condition). The students in the control group received no correlated instruction (control condition). Once again, both groups were instructed to design and build a second wind collector or make improvements to their original collectors. According to the technology teachers, most students opted to make improvements to their original collectors. Both the treatment group and the control group were given the same amount of time in the lab to physically implement improvements to their collectors. The output power was then measured, and the two groups were compared.

The findings of the study were presented on the pretest analysis of variance, the posttest analysis of variance to test the hypothesis, t-test analyses, and student interview analysis.

The following hypothesis was tested.

Ho: There is no significant difference between the technological problem-solving ability of technology education students receiving correlated instruction with science and mathematics (treatment group) and the technological problem-solving ability of technology education students who do not receive correlated instruction (control group).

Stated as a research hypothesis:

Ha: The technological problem-solving ability of students participating in the curriculum integration group (treatment group) will be superior to that of students not in the integration group (control group).

Since the literature and the logic of the experiment support the notion that the experimental group would out perform the control group, a one-tailed test was used.

Conclusions

The test of the hypothesis showed no significant difference between the treatment and control groups for wattage output at the posttest. The researcher failed to reject the null hypothesis. The researcher concluded that the integration of technology education, science, and mathematics appears to have no effect on the technological problem-solving ability of technology education students in this particular TSM Integration Activity.

Caution must be used in generalizing the results of this study since it involved only intact classes of eighth grade students in the Richmond, Virginia area. The school was chosen based on evidence of correlated technology, science, and mathematics instruction. Also, the treatment was not randomly assigned to the classes.

On the other hand, no evidence was found that the students were selectively enrolled in either the treatment or control group classes. In addition, the pretest showed no difference between the two groups.

Upon inspection of the data, the researcher made the decision to perform selected *post hoc* analyses. First, it was noted that the performance of the collectors for both the treatment and control groups improved between the pretest and the posttest. However, it was found that the treatment group outperformed the control group on the pretest, whereas on the posttest, the control group outperformed the treatment group. The researcher observed that a high proportion of control group students switched to building their collectors out of metal between the pretest and the posttest. A t-test revealed, however, that the performance of metal collectors was not significantly different from collectors made of other materials. Therefore, it was concluded that the use of metal does not necessarily result in better performing collectors. Second, it was observed that the majority of the students in the treatment group used a pitch angle that was approximately 15 degrees at the posttest whereas the control group students used greater pitch angles. The science teacher confirmed the fact that the students concluded as a result of an experiment that 15 degrees was the optimal pitch angle. This experiment involved the use of Tinker Toy-like wind collectors. It is possible that the results of this science experiment were not transferable to the actual wind collectors that the students designed and built in the technology lab. If this is true, then it might explain why the control group improved more at the posttest.

Though the study revealed no difference between those who received correlated science and mathematics instruction and those who did not, in terms of wind collector performance there was evidence that the students did, in fact, attempt to apply what they learned in the correlated instruction. The 15 degree pitch angle frequency is one example of this evidence. In addition, the sizes of the collectors produced by the treatment group students were closer to the specifications indicated in the Design Brief for the problem. Since this design constraint of collector size required the students to know how to calculate the volume of a cylinder, it is quite plausible that the students applied what they learned in the mathematics class about volume to the development of their solutions to the problem. Further evidence of science application was provided by interviews with the students. They showed that treatment group students tended to consciously apply science to the "Capture the Wind" problem. On the other hand, the control group seemed to depend on a combination of what the technology teacher taught them and what they observed about the performance of their collectors and those of other students. It appears plausible that students applied science and mathematics in their solutions to the wind collector problem. However, whether or not the students actually understood the underlying science and mathematics concepts was not within the scope of this study.

The results of this study are consistent with Anderson (1992) who found that focusing on the connections among disciplines may not improve problem-solving ability. However, unlike Anderson's study there was evidence that the students did, in fact, apply what they learned through science and mathematics instruction. Clayton (1989) found no evidence that science-related mathematics instruction improved achievement, but that it did improve learning and process skills. The study reported herein found evidence of similar skill development such as students being able to control variables in an experiment. The indications of science and mathematics application in this study support Gamsky's (1970) results that a treatment of correlated team teaching can benefit learning insofar as students applied science and mathematics.

Recommendations

The following recommendations pertain to the development of technology, science, and mathematics curriculum integration efforts and future research related to technology, science, and mathematics (TSM) curriculum integration.

1. Development of TSM curriculum integration materials that facilitate technological problem solving and the application of science and mathematics should continue based on evidence in this study that suggested students will, in fact, try to apply science and mathematics in solving technological problems. Such studies should focus on the effects of

TSM curriculum integration materials on technological problem solving as well as the effects of the materials on science and mathematics outcomes.

2. In this study, the technology teacher in the treatment group was not part of an interdisciplinary team at the school. It would be useful to conduct a parallel study to the one herein on the effects of TSM curriculum integration in a school where the technology education teacher is an integral part of the interdisciplinary team.
3. In this study, it was possible for students to observe the solutions of other students and integrate what the teacher taught them with their own ideas and their observations. Although it may be unrealistic in the traditional school setting, it is recommended that a similar study be conducted in which the students design, construct, and evaluate the technological problem solution independently of other students so that the effects of observing other solutions could be assessed.

Such a study should investigate the influence of other factors, such as learning styles, on the outcomes of technological problem solving.

4. The interviews used in this study provided evidence of the application of mathematics and science. It is recommended that a series of TSM integration research studies be conducted that employ primarily qualitative methods that will serve to complement quantitative studies conducted with similar populations.

5. Although is was beyond the scope of this study, it was difficult to determine whether or not treatment students understood the mathematics and science concepts taught. The researcher recommends that a test be developed to evaluate students on the extent to which they understand the mathematics and science concepts in TSM Integration Activities and similar activities.

6. In this study, students had to actually solve a problem for the pretest to assure that the treatment and control groups were not significantly different in technological

problem solving ability. It is recommended that demographic, socioeconomic, intellectual ability, and academic achievement data be collected in a similar study. Such a study would attempt to develop an index of problem solving ability from the data and might allow future researchers to avoid the need to actually have students solve a problem in order to pretest.

7. For the study reported herein, students seemed to focus on the specific science and mathematics instruction.

   It is recommended that a future study not employ the direct correlation of supporting science and mathematics concepts to the technology instruction and not limit the range of concepts students could apply to problem solutions.

   For example, the study of pitch angle would not be specifically taught in science during the technology instruction. Instead, the science content would be covered in the regular course of science instruction during the school year. During the technology instruction, students might feel free to apply any number of science concepts they learned during the year.

8. Very few schools are integrating technology education, science, and mathematics, and this limited the sample size in this study. Identifying schools that are conducting TSM integration is difficult. In anticipation that TSM integration will be implemented on a widespread basis, it is recommended that larger samples be used to fully investigate the effects of TSM integration on race and gender and to increase the power of the statistical analyses.

   Additionally, it is recommended that further experiments on the effects of TSM curriculum integration be employed that go beyond the scope and depth of this study.

   Finally, to facilitate the identification of populations and access to them, it is further recommended that consortia of colleges of education and local school systems, in

Virginia and elsewhere, be founded. Their activities would include the coordination of research and would assist in matching research activities with local school systems.

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Appendix A

An Adapted TSM Integration Activity: "Capture the Wind"

Not available on-line.

For information on *Technology, Science Mathematics Connection Activities*, contact: Glencoe McGraw-Hill.

For information on the Technology, Science, Mathematics Integration Project, contact:

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