Articles

Does Integrating Technology, Science, and Mathematics Improve Technological Problem Solving? A Quasi-Experiment

Vincent W. Childress

Introduction

Most educational reform reports since the mid 1980's call for higher standards for curricula, higher standards for student achievement, and new approaches to teaching and learning. Many of these reports call for reform in technology, science, and mathematics education and integration of the three curricula. These calls for educational reform and curriculum integration have led many technology educators to understand the urgent need for research like the study reported herein.

The Need for Research

In 1958, Mayhew, writing on reform in higher education, emphasized the need for research in curriculum integration. "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" (p. 148). Little has changed since 1958. Loepp (1992) and Foster (1995), recognized the lack of research studies on curriculum integration and the limitations encountered by researchers. LaPorte and Sanders (1995a) cited research concerning 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.

Related Research

Findings are inconclusive among the few integration research studies related to this study. It is difficult to identify patterns among them. Some of the studies that used samples larger than 100 subjects and treatments longer than eight months found significant differences between the curriculum integration treatments and the control groups. However, other studies of comparable size and duration found no significant differences. Studies using smaller samples and shorter treatment periods also had conflicting results. (Among other studies, see

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Vincent W. Childress is Assistant Professor at North Carolina Agricultural and Technical State University.

Anderson, 1992; Brusic, 1991; Clayton, 1989; Dugger and Johnson, 1992; Dugger and Meier, 1994; Graves and Allen, 1989; Scarborough and White, 1994.)

The Technology, Science, Mathematics Integration Project

The Technology, Science, Mathematics (TSM) Integration Project, with support from the National Science Foundation, developed a set of technology activities called the *Technology, Science, Mathematics Connection Activities* (LaPorte and Sanders, 1995b). They are designed to help middle school teachers correlate planning and classroom instruction among the three disciplines. The activities do not constitute a curriculum *per se*, but are units that set up technological problems for students to solve. In the process, students learn concepts from each of the three disciplines and apply what they learn to the design, construction, evaluation and redesign of the technological solution.

Each activity is divided into several sections. The students are provided with a design brief that introduces the problem, specifies any design constraints or limitations to the problem solution, and explains how the students' solutions will be evaluated. The Teacher Overview provides the teachers with an overall explanation of how the activity is organized, and it includes an instructional sequence chart and some details of how the technology, science, and mathematics concepts are interrelated. Finally, the Technology, Science, and the Mathematics Components provide detailed suggestions for instruction and certain content for each subject area (LaPorte and Sanders, 1993).

Purpose

The purpose of this study was to determine if TSM curriculum integration improves the ability of technology education students to solve technological problems. The research question was:

> Do technology education students achieve in technology better when their technology education teacher correlates planning and instruction with their science and mathematics teachers?

The study examined student solutions to technological problems and whether the solutions were better in the experimental group or in the control group. The study also examined whether or not students were attempting to apply the science and mathematics they learned.

Methodology

The researcher used a quasi-experimental, non-equivalent control group design to measure the effects of TSM curriculum correlation. While there were limitations within the methodology of the study, it can provide valuable guidance for future quasi-experiments in curriculum integration. This study's primary value is that it provides a pilot for quasi-experiments in technology education curriculum research and identifies the various limitations to such research. Feedback from field tests of the *Technology, Science, Mathematics Connection Activities* suggested that implementing curriculum integration is both difficult and requires commitment among the teachers involved to overcome the structural constraints to implementation (Sanders, 1993). The paramount consideration is common planning time for the teaching team during the regular school day. Common planning means teachers must commit to regular meetings and work together. Teachers also must be committed enough to work around student scheduling problems. In the context of TSM implementation, the teacher team may not share many students in common. The technology teacher and students may need to visit the science and mathematics classes to explain how the technology relates to the science and mathematics content. Science and mathematics teachers also use the technological solutions developed in technology class as teaching aids.

Based on this feedback, the sampling frame was composed of middle schools that had demonstrated interest in curriculum integration through participation in workshops and seminars prior to the study. While these schools may not have attempted to implement TSM integration, they would at least be more likely to have a group of faculty who have worked together in considering curriculum integration. These schools may also have more likely identified teachers who can work together and who have a common planning time.

In an attempt to control confounding variables, the researcher delimited the sampling frame to those schools that had two technology education teachers who both taught the same grade level and had access to general technology education laboratories. Theoretically, using one teacher would control for teacher differences. Realistically, it seems unlikely that a teacher would be able to isolate his or her behaviors as they relate to the treatment and control conditions. In an attempt to control for differences between the two technology teachers, an adapted set of treatment and control materials was employed to guide the teachers. Most of the few schools that met the criteria were not able to schedule the quasi-experiment. After identifying three schools that met the criteria and could schedule it, one school declined to participate because the academic teachers were too busy. A second school was used in the pilot study, and the third school was selected as the study cite. The selection of the school for the study was fundamentally a convenience sample.

Due to scheduling, the science and mathematics teachers were required to deliver the treatment instruction during their common planning period in the technology education lab, but they were committed to the assignment. TSM Integration Project field test results identified the lack of common planning as a major constraint to curriculum correlation. One of the strategies schools used to overcome this was to invite teachers into selected classes during their planning periods (Sanders, 1993). For this study, the only class of eighth grade technology education students available during this planning period was designated as the experimental group. The researcher selected one particular class of students for the control group because their schedule most closely matched that of the experimental group students. Any unforeseen interruptions experienced by one group would likely be experienced by the other. There were 17 students in the experimental group and 16 students in the control group. The convenience sample and the small sample size may have had fundamental effects on the findings of this study.

One of the *TSM Connection Activities*, “Capture the Wind,” was selected and adapted to provide the instructional materials for the study. This activity was used as the basis for presenting the problem that both groups of students were to solve: “Design and build a device that efficiently transforms wind energy into electrical energy.” Students designed and constructed wind collectors.

There were two iterations of problem solving throughout the course of the study. The first was prior to the pretest, and the second was after the pretest. No treatment was administered during the first iteration of problem solving. Students in both the experimental and control groups received the same instruction on designing wind collectors, and both groups had the same amount of time for instruction and lab work. The topics covered by the technology education teachers were as follows:

- Review of material processes
- History of wind power
- Wiring of the generator
- Demonstrate the generator without the use of a collector
- How to mount collectors on the generator
- Materials that can be used
- Collector design considerations
  - should the collector rotate on a horizontal or vertical plane
  - within the volume constraint, should students maximize the diameter or the depth
  - how to measure volume to see if collectors are too large
  - what to do to the restricted flow of air around the hub area
  - should collector mass be minimized or maximized
  - does the collector need to be rigid in the wind

The effectiveness in solving the problem was determined by measuring the actual performance of the student-made wind collectors. Each wind collector was connected to a small direct current generator and turned by a fan to hold wind speed constant. A voltmeter was connected across a fixed load resistor. An ammeter was connected in series with the circuit, and the voltage and amperage were measured simultaneously. The electrical output of each solution was measured using the same generator and under the same conditions. The voltage and amperage readings were multiplied to calculate the power output in milliwatts from the generator for each wind collector. The exact same procedure was used for both the pretest and the posttest.

The pretest data were collected the day after the first iteration of instruction and problem solving (15 class periods). The researcher performed an analysis of variance and found no significant difference between the experimental group and the control group in performance on the pretest. Thus, he did not consider the two groups to have significantly different problem solving ability as it relates to the wind collector problem prior to the administration of treatment. The pretest findings are tabulated in Table 1.

Table 1

Pretest Analysis of Variance for Milliwatts Generated

Source	*df*	*MS*	*F*	*p*

Group	1	33.5	0.18	0.7409
Error	31	301.1		
Total	32			

Group	*n*	*M*	*SE*
1. Control	16	25.06	4.33
2. Treatment	17	27.08	4.20

Treatment began for the experimental group the day after the pretest. The objective for students in both groups was to improve the performance of the wind collectors (a second iteration of problem solving). The experimental group received one and one-half class periods of science instruction and activity and one class period of mathematics instruction. This instruction was in addition to the time the treatment group had to physically improve their solutions. The amount of time that the treatment and control groups physically labored to implement collector improvements was equal.

The materials that the experimental group received included the technology, science, and mathematics content that was considered essential to the design, construction, and evaluation of the wind collector. The material received by the control group was identical except that the science and mathematics sections were deleted.

The concepts taught by the science and mathematics teachers were directly related to the technological problem that the students were attempting to solve. The science teacher taught students how the force of the wind can be redirected by the wind collector solutions. This included a qualitative demonstration. The science instruction also included experiments designed to identify the optimal pitch angle of wind collector blades using Tinker Toy-like wind collectors. During the mathematics instruction, students learned how to calculate the maximum volume within which the wind collector size was constrained, and how to maximize the collector dimensions within the volume constraint. The mathematics instruction also taught students how to tabulate data and graph relationships between (1) the pitch angle and wind collector power output, and (2) between the number of blades and the wind collector power output.

The control group received no science or mathematics instruction during the second iteration of problem solving. These students proceeded with the improvement of their solutions over five class periods after which the solutions were collected and stored until the posttest.

During the second iteration of problem solving, the researcher randomly selected six students from each group to interview individually. The questions asked were designed to see if experimental group students were attempting to apply science and mathematics principles as they solved the problem. For control group students, the exact same questions were used to identify what factors influenced their designs. The questions, listed below, were phrased to avoid response bias. The questions were phrased in such a way that it was 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?*
   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 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.
4. *Why are the blades on your wind collector bent at an angle?*
5. *Why did you use X number of blades on your wind collector?*
6. *How do you know that your wind collector is not larger than 122 cubic inches/2000 cubic centimeters?*
7. *If you made more than one change to your wind collector, how can you tell which change made it improve or get worse?*

The posttest data were collected from both groups on the same day after the experimental group completed their improvements. The experimental group received the same amount of lab work time to make their improvements.

Findings

The researcher was attempting to measure the effects of TSM integration on the technological problem solving ability of eighth grade technology education students. Analysis of variance was used to test the research hypothesis. Table 2 shows that there was no significant difference between the groups on the posttest, and the researcher failed to reject the null hypothesis. It is important to note that both groups improved. The mean electrical power produced by the solutions slightly favored the experimental group in the pretest and the control group slightly in the posttest. Upon inspection of the data for the experimental group, the researcher found that the solutions of ten students increased between the pretest and the posttest; the solutions of six students produced less power. All but two solutions improved for the control group on the posttest. This could partially explain why the mean of the control group went from being lower in the pretest to higher in the posttest.

Table 2
Posttest Analysis of Variance for Milliwatts

Source	*df*	*MS*	*F*	*p*

Group	1	350.1	1.45	0.2374
Error	31	241.1		
Total	32			

Group	*n*	*M*	*SE*
1. Control	16	36.71	3.88
2. Treatment	17	30.19	3.76

Why did more experimental group students perform lower on the second iteration than on the first? Post hoc t-test analyses were used in an attempt to partially explain these results. The adapted *TSM Connection Activity* stipulated that the wind collectors could not exceed a specified volume. The mathematics instruction was correlated with the *Connection Activity* in order that experimental group students could maximize the size of their wind collectors within the volume constraint. The experimental group did not maximize their solutions to the limits of the volume constraint. Nevertheless, there was, in fact, a significant difference in collector size favoring the experimental group as shown in Table 3. There was no mechanism within the design of the study to explain why experimental group students failed to maximize the sizes of their collectors to within the limits specified.

Table 3
T-Test for Size Constraint

Dependent Variable: Collector Size in Cubic Inches

Group	*n*	*M*	*SE*	*CI*		*p*
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 of problem solving, the experimental group received science instruction related to the pitch angle of the collector blades. This science instruction included an experiment in which the 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 shows the large frequency of students using 15 degrees of pitch angle after science instruction. Control group students used a wide variety of pitch angles.

Table 5 categorizes the responses of the students that were interviewed as to why they thought that their second solution would perform better than their first solution.

Table 4
Distribution of Experimental Group by Pitch Angle

15 degree pitch angle:	10 students

Other pitch angle:	7 students

Table 5
Categorized Responses of Interviewed Students Concerning Why They Felt Their Second Solution Would Perform Better Than the First (n=6)

Responses	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

Responses	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

Conclusions

It is possible that the results of the science experiment on pitch angle 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 in the posttest; or more specifically, why some treatment group collectors produced less power in the second iteration.

Although the study revealed no significant 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 experimental group were closer to the specifications indicated in the adapted *TSM Connection Activity*. Since the wind collector size constraint required 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.

Further evidence of science application was provided by interviews with the students. The interviews provided the most positive findings in the study. They showed that experimental group students tended to consciously apply science to the wind collector problem. On the other hand, the control group students 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 treatment group 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 beyond the scope of this study. The teachers involved with the experiment agreed with these findings.

Discussion

The results of this study have implications for the development of TSM curriculum integration efforts and future research related to TSM integration. 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. In future studies, post-experiment student interviews may be helpful in explaining results. Such an interview may have provided answers as to why some experimental group students in this study scored lower on the posttest and why the collector sizes were larger but not optimized.

In this study the technology teacher in the experimental group was not part of an interdisciplinary team at the school. It would be useful to conduct a parallel study to this one in which the technology teacher is an integral member of the interdisciplinary team that shares all students among team members.

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

In this study, students had to actually solve a problem for the pretest to assure that the experimental and control groups were not significantly different in ability to solve the particular technological problem. 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. Such data could also be collected *a priori* for an ANCOVA in a better attempt to explain the results.

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. It would be interesting, albeit difficult, to conduct a similar study in which the students work independently so that the effects of observing other solutions could be assessed. This might be accomplished in a “lab school” or clinical setting.

Because it is conceivable that the results of the pitch angle experiment were not transferable to the types of solutions that the students were working on, similar studies should use the actual student-made solutions as teaching aids and demonstration props. This is supported by recommendations made in the *TSM Connection Activities* (LaPorte and Sanders, 1995b).

In spite of the foregoing attempt to explain the results of this experiment, the most fundamental constraint to this study was the lack of probability sampling and the small sample size. Researchers should develop working partnerships with the public schools in order to pursue research interests through long-term planning. Such a relationship would ensure that future studies are able to identify a number of viable sites and are able to use random assignment of groups in experiments with complicated treatments such as curriculum integration.

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