
Current Editor:
Richard A. Walter raw18@psu.edu

**Journal of Industrial Teacher Education**
**Volume 39, Number 3 • Spring 2002**



# Designing and Implementing an Integrated Mathematics, Science, and Technology Curriculum for the Middle School

**Richard E. Satchwell**
**Illinois State University**

**Franzie L. Loepp**

**Illinois State University**

In 1991, the President of Illinois State University encouraged three Distinguished Professors, Drs. Dossey, Fitch, and Loepp (mathematics, science, and technology, respectfully), to establish an organization on campus called the Center for Mathematics, Science, and Technology (CeMaST). The originators of CeMaST immediately conceived a plan to develop an integrated curriculum that represented each of their disciplines. A proposal was written and submitted to the Instructional Materials Development (IMD) program in the Elementary, Secondary, and Informal Education (ESIE) Division of the National Science Foundation (NSF). Funding was awarded in 1992 to design a standards-based, integrated 7th grade curriculum. Additional funding to develop the 8th grade curriculum was received in 1995, and to develop the 6th grade curriculum in 1999. This Integrated Mathematics, Science, and Technology curriculum project became known as "IMaST."

The purpose of this article is to discuss the issues associated with the design, development, and implementation of the IMaST curricula and to provide insights to those initiating similar endeavors by answering specific research questions and by making recommendations based on that research.

## Project Overview

One of the initial challenges faced by the IMaST Project was to design a framework upon which all three disciplines could agree. The national standards for all three promote connections between disciplines; however, a number of possible approaches for curriculum design can be used to achieve these connections. An *intradisciplinary* curriculum focuses on the integration of different areas within one discipline. For example, an intradisciplinary science program might include curricula that integrate areas within science such as chemistry and biology. The *Prime Science* (NSF ESI-9255829) curriculum is one example of an intradisciplinary curriculum. *Interdisciplinary* curricula focus on instruction within one domain, while supporting the content with implicit connections between disciplines (PRIME Science Education Group, 1998). An example of an interdisciplinary curriculum is the NSF-funded *Learning by Design* (NSF ESI-9818828) project (Crismond, Holbrook, Kolodner, & Ryan, 1998). An *integrated* curriculum is one with an explicit assimilation of concepts from more than one discipline. As much as possible, integrated curricula apply equal attention to two or more disciplines (Huntley, 1999). This integration paradigm best matched the needs of the IMaST curriculum because of its concern for equality between all three disciplines. Other examples of integrated curricula include *A World in Motion*, published by the Society of Automotive Engineers (1996), and the *Technology, Science, Mathematics Integration Project* (NSF MDR-9150085), later published by Glencoe (Laporte & Sanders, 1996).

The IMaST curriculum is perhaps the only full middle school curriculum in the U.S. that integrates technology, science, and mathematics. Other features of the curriculum include connections to the language arts and social sciences, as well as readings that profile typical careers related to the curriculum content.

After reaching consensus on a framework for connecting mathematics, science, and technology, the Project turned its attention to curriculum development. This process involved the identification of shared themes based on the national mathematics standards, devised by the National Council for Teachers of Mathematics (NCTM, 1989, 2000), and the *National Science Education Standards* (NSES), developed by the National Research Council (NRC, 1996). The *Standards for Technological Literacy*, devised by the International Technology Education Association (ITEA, 2000), were not officially available until the year 2000. However, the IMaST curriculum does address many of these standards.

In addition to the national standards for each discipline, IMaST Project staff considered the benchmarks developed by the American Association of the Advancement of Science (AAAS, 1993) as it selected themes for each curriculum module. The themes selected embody a high potential for student interest, authentic problem-solving activities, and rich content for mathematics, science, and technology. Initial themes identified by the Project staff were included in each of the proposals to the National Science Foundation. Examples included *Patterns of Mobility* (grade 6), *Manufacturing* (grade 7), and *Systems* (grade 8). Each theme had one clear objective, such as the module titled *Systems*, in which students are expected to be able to use a systems model to analyze, design, and model natural and human-made systems. Each theme also contained three to five key concepts, such as "systems model," "relationships," and "variables." These thematic objectives and key concepts served as a guide for the selection of content in each of the subject areas and were derived by carefully cross-referencing the standards from each discipline (see the Appendix for a complete list of modules and their respective objectives and key concepts).

*The Project Staff*

A team of researchers representing mathematics, science, and technology led the Project. Three Co-Directors oversaw the domain-specific content to ensure its appropriateness, particularly in delivering the various standards.

A full-time Project Coordinator oversaw the Project. The Project Coordinator was responsible for locating schools for field test sites, recruiting Design Team members, editing the materials to ensure equal representation of all three disciplines, and scheduling the development of the curricula. In addition, the Project Coordinator oversaw the collection of data so that informed revision of materials could take place. The Project Coordinator also managed the work of three full-time curriculum specialists.

National searches were conducted for curriculum specialists with extensive teaching experience and demonstrable writing skills from the fields of mathematics, science, and technology. They were responsible for making sure that the materials conformed to an agreed-upon format before being tested with students. Together, the specialists prepared the IMaST student editions as well as comprehensive teachers' guides. They worked as a team to ensure that integration took place, and revised ideas generated by a "Design Team" of master teachers. The curriculum specialists also worked to ensure equal coverage of the standards from their respective disciplines.

*The Design Team*

Each three-year developmental phase of the IMaST project included a Design Team made up of the "best of the best" middle school mathematics, science, and technology teachers, forming a team of nine in total. The Design Team selection included a competitive application process that considered applicants' demographics, writing abilities, and teaching experience within their discipline.

The Design Team was comprised of teachers who were all currently teaching in schools. The Design Team worked in conjunction with the Project staff to lend a valuable "outside" perspective to the development of curricula, the generation of ideas, revisions, and the application of national standards. Their role was to help review the proposed themes and help consider the national standards to include in each module.

The Design Team helped the Project staff generate an overall objective, as well as identify the key concepts for each thematic curriculum module. Subsequently, they developed a series of discipline-oriented objectives that fully aligned with national standards. To introduce each module, the Design and Project teams created an introductory "challenge" designed to pique the interest of the students and introduce them to the theme.

After determining the module themes, objectives, and key concepts the teams generated developmentally appropriate, standards-based, activities and assessments for each discipline. While developing the activities, the Project worked very hard to find opportunities for integration. It was also during the activity development that the Project adopted a four-phase learning cycle that each activity would come to conform to throughout the curriculum.

*The Curriculum Development Process*

The curriculum development process resulted in 16 thematic curriculum modules (see the Appendix for a complete list). The modules were field tested over three years, revised after each test, and prepared for commercial publication.

During the field-testing process, each module underwent a thorough review by mathematics, science, and technology content experts. One content expert was selected for each discipline to review the domain-specific content for each module. Feedback from field-testing and content experts was compiled into a "master feedback copy" and provided to the Design Team and Project staff to use as they revised the materials and prepared each field-test edition. Figure 1 graphically illustrates the development process.

The administrator and teachers from each field-test site experienced one week of inservice training during the summer before each year of testing. Project staff made site visits (approximately four per year) to provide ongoing support and to gather information from administrators, teachers, and students with respect to implementation of the program.

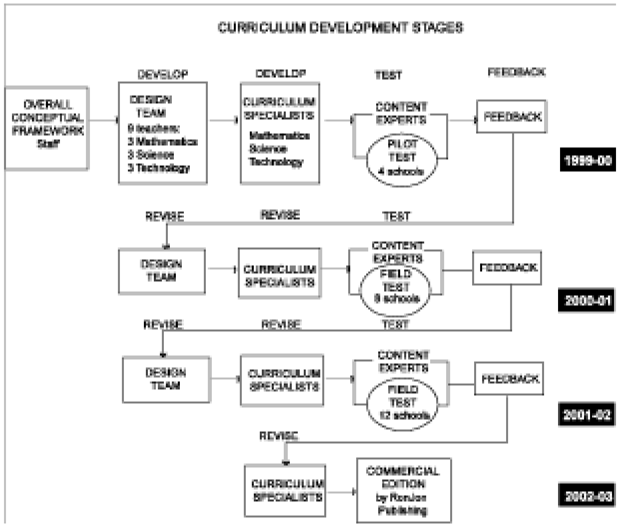


*Figure 1*. The IMaST Curriculum Development Process

## The IMaST Learning Cycle

Research indicates that students learn best when they are encouraged to construct their own knowledge of the world around them (Colburn, 1998; Lawson, Abraham, & Renner, 1989). The IMaST learning cycle stems from constructivist learning theory and allows important concept development to take place in a structured venue. The theme for each IMaST module provides the structured setting for the conceptual development for mathematics, science, and technology.

Students proceed through a series of conceptual learning cycles that include open-ended, hands-on activities. Each learning cycle relates to the module's thematic topic and addresses an important concept related to mathematics, science, or technology.

The first phase of each learning cycle is called *Exploring the Idea*. Students engage in hands-on activities that enable them to start to discover concepts related to each discipline. Students work in small groups testing their initial ideas about the concept being studied. They test their ideas by taking things apart, making predictions, observing, and recording their explanations in a wide variety of technological, mathematical or scientific contexts. The activities developed in this phase challenge common assumptions and preconceptions about the module's key concepts. For example, students explore the habitat requirements for raising fruit flies in the context of science, while calculating the required dimensions in mathematics, and exploring possible design options in technology. Throughout the *Exploring the Idea* phase, students record evolving ideas and relevant evidence and assess, modify, and/or reject their initial ideas. Throughout this process they are developing new understandings. These activities target technology, science, and mathematics benchmarks or standards through age-appropriate experiences.

As students are completing the *Exploring the Idea* phase, the instructor facilitates the second phase of the learning cycle, entitled *Getting the Idea*. During this phase the instructor leads the class to consensus about the key concepts under investigation, clears up misconceptions, and facilitates reflective activities/discussions regarding the concepts explored. Students employ techniques such as class presentations, class data compilation, and wall charts in order to express and share their understanding of the concepts explored. This is an opportunity for teachers to identify what students know and what they need to know about the concepts under investigation. Questions provided in the teacher's guide help instructors lead class discussions to determine if students are developing appropriate conceptual understanding.

The next phase of the learning cycle is *Applying the Idea*. The purpose of this phase is to provide students with opportunities to see the possibilities, and perhaps limitations, of the concepts explored in a variety of new contexts. Whereas the *Exploring the Idea* phase engages students in planned, but open-ended, activities so that they can reach consensus about targeted concepts, *Applying the Idea* allows students some latitude to explore their own questions or insights using available resources. This phase encourages students to apply the various technological, mathematical, or scientific concepts in a variety of contexts as prescribed by the national standards. Returning to the example of the fruit fly activity, students apply what they have learned about habitat requirements and design to devise and build a habitat to raise fruit flies in accordance with the mathematical concept of exponential growth.

The fourth phase of the IMaST learning cycle allows for further integration of mathematics, science, and technology. During this *Expanding the Idea* phase, students are encouraged to apply what they have learned about a particular concept into a new context beyond mathematics, science, and technology. For example, students predict the effects of the exponential growth of humans on our environment, and society. The sequence of learning cycles from each discipline enables students to discover connections between mathematics, science, and technology.

The Project writing team developed optional, "authentic" student assessments and placed them in the teacher's guide after each learning cycle. The assessments present students with authentic tasks and include a scoring rubric. Furthermore, each module contains a final assessment, an activity that seeks to measure student achievement of the module objective and requires them to connect all the key concepts studied in mathematics, science, and technology.

## Selected Research Questions

IMaST staff members have learned many things about developing and implementing standards-based curricula during the Project's existence. Eight primary research questions have guided this developmental research project for nearly a decade.

*1. What procedures of the development protocol are most effective in assuring the production of high quality, useable curriculum material?*

Five primary feedback tools were helpful during the research and development process. They included activity feedback checklists; notes written by teachers in the teacher's edition; structured site visit reports; assessments from content experts in mathematics, science and technology; and feedback from the external evaluator.

The activity checklists consisted of six Likert-type items plus space for open-ended comments. The checklist page was placed directly after the learning cycle in the field-test version of the teacher's edition of each module. This encouraged teachers to provide an immediate response regarding the relative effectiveness of the learning cycle.

Teachers were also encouraged to jot down their reactions to each of the learning cycles in the margins of their teacher's edition. All field test teachers returned their teaching materials to the Project office where Project staff created a "master" version by compiling comments from all teachers. This technique had the greatest impact on the revision and improvement of modules.

A third form of feedback involved Project staff making visits to each of the field-test sites at least four times per year. Although the purpose of the site visits was primarily to provide support and assistance to the teachers, comments made by students and teachers proved helpful for the revision and refinement of the curriculum.

Content experts from each of the three disciplines reviewed each module for its domain- specific content. Their reviews, guided by several open-ended questions, helped to establish the validity of the curriculum material. The Project staff considered their comments during the revision process.

An external evaluator was contracted, as required by the NSF, to oversee the Project. The Project's evaluator visited or called all field-test sites to interact with administrators, teachers, and students. He used a structured interview schedule to assure the acquisition of information on specific topics. He also reviewed the data received from teachers, site visit reports, and experts and compared those data to the changes that were made as the materials moved from one edition to the next. He then furnished Project leaders with a written report of his findings.

*2. How is alignment with national and state standards and subject benchmarks maintained by the procedures of the Project?*

Alignment with the national standards was a continuous process. Although the standards guided the initial stages of curriculum development, it was important to maintain this relationship. Several procedures helped to address this issue. First, external reviewers such as the "Discovery Project" at The Ohio State University reviewed a series of modules and found them to align with national mathematics and science standards. Second, Project staff fulfilled requests to map the IMaST materials to state frameworks and objectives. This has been completed for the states of Texas, Washington, Louisiana, Michigan, Massachusetts, Ohio, Virginia, and Illinois.

*3. What are the barriers to the implementation of an integrated mathematics, science, and technology program?*

Shea (1994) attempted to address this question in her master's thesis. Shea found that preparation time, required materials and resources, storage requirements, grading procedures, curriculum content, and teacher attitudes play a role in the successful implementation of an integrated curriculum. As one would expect, when two or more teachers are involved in a common curriculum it is important for them to have a common planning time. Most schools have not arranged for this to take place during the regular school day. In most cases, this adds to the teachers' preparation time. Technology teachers have laboratories and are used to dealing with the purchase and storage of materials. This is not the case for mathematics teachers and some of the science teachers. There is resistance from mathematics and some science teachers to actually have students involved in hands-on activities because of the need to make materials available and to deal with inventory, storage, and student safety issues.

Authentic assessment is also a new idea for teachers who are accustomed to determining grades with worksheets and objective tests. The change to assessing student progress while they are engaged in projects and using activities graded with use of rubrics is a procedure that meets resistance from some teachers.

In an integrated program, all teachers find themselves needing to learn new content. Technology teachers learn mathematics and science. Mathematics teachers learn science and technology and science teachers learn mathematics and technology. Some teachers do not like to admit that they do not know the content students are learning in other disciplines.

Teacher attitudes had a significant influence on the implementation of the IMaST curriculum. In some cases an administrator and perhaps one teacher was enthusiastic about integrated learning, while the other teachers resisted change. This situation had the potential to cause positive professional growth, but also resulted in a negative attitude on the part of some of the teachers. The collective attitude of the teachers had a direct impact on student learning.

Visits made to our field-testing sites revealed that classroom management played a role in the implementation of the IMaST curriculum. The management of open-ended, hands-on tasks where groups of students interact is much different from the traditional lecture style of instruction in mathematics and in most science classrooms. On the other hand, technology teachers were usually able to manage groups of students engaged in a variety of activities.

Added to the list of implementation barriers was the influx of high stakes testing. Schools on probation or those with declining test scores were reluctant to take on an integrated program. However, as measures of student achievement reported in the next section indicate, students engaged in hands-on, integrated activities can outscore those in traditional education programs.

*4. Is student achievement affected by integrated curricula?*

Over the past several years, student achievement has been measured using a number of indicators. Initially, there was a concern that the computational skills of IMaST completers may not be as strong as students in traditional mathematics curricula. The standardized Stanford Achievement Test was utilized to determine whether this was the case. Results showed that even though IMaST students did not spend a great deal of time practicing computations through the use of worksheets, they performed at the same level or higher than students in traditional programs.

The most promising measure of student achievement was the results of a sub-test of the Third International Mathematics and Science Study (TIMSS). During the spring of 1997 and the spring of 1998, IMaST completers took mathematics and science TIMMS sub-tests. The math and science sub-tests each consisted of 36 items. Twenty-two of the mathematics and 20 of the science items were multiple choice. The remaining items in each content area were open-ended and required a free written response after having solved the problem. Students filled out an electronic score sheet for the multiple choice items and wrote their responses to the open-ended items in the test booklet.

Scoring protocols were supplied by TIMSS and adopted for the Project. Present or former science teachers were trained on the scoring protocols as readers. They read the item, compared the response to the protocol, and rated it as either "A" (correct), "B" (partially correct), "C" (incorrect), "D" (illegible response), or "E" (blank). These responses were coded on the student's electronic score sheet.

Reliability of scoring was a concern. In order to enhance consistency in scoring, each reader was assigned pre-tests and post-tests from the same school. In addition, 60 randomly selected tests were pulled for a reliability check. In addition to the primary reader, two others scored both the mathematics and science open-ended items of those 60 tests. Table 1 contains the correlation coefficients calculated among the three readers. All inter-rater correlations are .91 or greater, which appears to be quite satisfactory. The coefficients should not be assumed to be reliability estimates of the test, however. Errors in measurement, such as student fatigue, questionable motivation, and other student variables, are present, just as they are in so-called objective measurements.

**Table 1**
*Inter-rater Reliabilities Among the Readers*

| Variable | Mean | SD | Correlation Matrix | | |
|---|---|---|---|---|---|
| | | | Rater 1 | Rater 2 | Rater 3 |
| *Mathematics sub-test (n=60)* | | | | | |
| Math rater 1 | 9.23 | 7.07 | 1.00 | 0.91 | 0.93 |
| Math rater 2 | 8.87 | 7.01 | 0.91 | 1.00 | 0.97 |
| Math rater 3 | 8.95 | 6.87 | 0.93 | 0.97 | 1.00 |
| *Science sub-test (n=60)* | | | | | |
| Science rater 1 | 12.22 | 7.37 | 1.00 | 0.91 | 0.92 |
| Science rater 2 | 11.95 | 7.20 | 0.91 | 1.00 | 0.96 |
| Science rater 3 | 12.04 | 7.31 | 0.92 | 0.96 | 1.00 |

This research question addresses potential differences in performance depending on the level of cognition. The impact of constructivist learning should especially impact thinking skills of the type found in mathematics problem solving and science processes. One of the attractive features of the TIMSS is that items are available which tend to address various cognitive levels. In the mathematics sub-test, the selected items are grouped into four cognitive levels, including: (a) *knowing mathematics* (7 items); (b) *routine mathematics procedures* such as addition, subtraction, multiplication, division, (7 items); (c) *complex procedures* (6 items); and (d) *problem solving* (16 items). The first three scales were considered too short to be reliable estimates. Therefore, two sub-scales were formed from this breakdown. The first was a twenty-item scale called "mathematics procedures" which included the first three cognitive levels of *knowing mathematics, routine procedures, and complex procedures*. The second sub-scale was left as "mathematics problem solving," comprised only of items from the fourth cognitive level.

The science sub-test contained items from five cognitive levels including: (a) understanding simple information (8 items); (b) *understanding complex information* (10 items); (c) *theorizing, analyzing, and solving problems* (13 items); (d) *using tools, routine procedures, and science processes* (1 item); and (e) *investigating the natural world* (4 items). As in mathematics, two sub-scales were formed from the items. The first, called "knowing science," contained the first two levels, while the second, "science processes," was comprised of the latter three cognitive levels. The resulting sub-scales in both mathematics and science allowed an examination of the differential effects of the IMaST curriculum on the two types of learning outcomes.

The direct comparison of students who experienced the IMaST curriculum versus those who did not required that both groups be represented in each school. Although no scientific random assignment took place, the assumption was made that selecting students from the same schools would control at least some extraneous variables. (The analysis of covariance model would also serve as some control over assignment bias.) Since two schools did not provide data for such a comparison group, the scores of students from those schools were eliminated from this analysis.

The number of subjects from each school included in the data set is depicted in Table 3. Although there appears to be some disproportionality across schools, the number of IMaST and traditional students are similar enough to assume no bias.

**Table 2**
*The Students Included in the Data Set*

| | **School** | | | | | | |
|---|---|---|---|---|---|---|---|
| **Group** | 1 | 3 | 4 | 5 | 6 | 8 | Total |
| IMaST | 67 | 24 | 22 | 29 | 130 | 21 | 293 |
| Traditional | 35 | 17 | 24 | 60 | 94 | 16 | 246 |

The analysis employed a rather complex general linear model. The basic design was a two-by-two analysis of covariance with repeated measures, as described in Winer, Brown, and Michels (1991, p. 820). The two groups, IMaST versus Traditional, comprised the between groups variable, while the two sub-scales (Procedures vs. Problem Solving in mathematics; Knowing vs. Processes in science) comprised the repeated measure. Subjects, or students, are nested within the group and repeated across the sub-scale dimension. The dependent variable was the sub-score obtained by the students (the two sub-scale scores for each student appeared in the dependent variable). The pre-test sub-scale scores comprised the covariate. The model was run for each of the mathematics and science sub-tests.

The design provided the opportunity to analyze the differential effect of the IMaST program by examining the interaction of group by sub-scale in the model. The expectation was that the difference between the groups would be greater for problem solving than for procedures with the mathematics sub-scales, and greater for *processes* than *knowing* with the science sub-scales. The primary research question, addressing the overall difference between the two groups, was examined as the main effect GROUP in the model.

The analysis of covariance summary table for the mathematics sub-test appears in Table 3, while the adjusted or least square means for the tested effects appear in Table 4. The test of the hypothesis regarding the Group by Cognitive Level interaction (GROUP*COGLEVM), yielded $F$=.62 ($p>.05$). That effect, therefore, was not statistically significant, so no evidence exists in the data to indicate a differential effect of IMaST on mathematics procedures as compared to mathematics problem solving.

The primary question regarding the effect of IMaST on mathematics performance is found in the GROUP effect of the model. The *F*-value of 7.14 (p<.01) provides evidence that, over both cognitive levels, a difference exists in the effect of IMaST and Traditional instruction on mathematics scores. The third column of Table 4 indicates an adjusted mean of 15.54 for the IMaST group compared to 14.30 for the Traditional group.

**Table 3**
*Analysis of Covariance Between Groups and Cognitive Levels for the Mathematics Sub-test*

| **Source** | ***df*** | **Sum of Squares** | **Mean Square** | ***F*** | ***p*** |
|---|---|---|---|---|---|
| MTHPRE | 1 | 31504.72 | 31504.72 | 2736.18 | 0.0001 |
| GROUP | 1 | 353.78 | 353.78 | 7.14 | 0.0078 |
| SUB (GROUP) | 511 | 23133.24 | 49.55 | | |
| | | | | | |
| COGLEVM | 1 | 2860.23 | 2860.23 | 248.41 | 0.0001 |
| GROUP*COGLEVM | 1 | 7.11 | 7.11 | 0.62 | 0.4324 |
| COGLEV*SUB (GRP) | 510 | 5872.20 | 11.51 | | |
| **Total** | 1025 | 63386.84 | | | |

*Note*. Number of observations in data set = 1078. Due to missing values, only 1026 observations were used in analysis.

**Table 4**
*Adjusted or Least Square Means in Mathematics by Cognitive Level*

| **Group** | **Math Procedures** | **Problem Solving** | **Across Levels** |
|---|---|---|---|
| IMaST | 17.72 | 13.35 | 15.54 |
| Traditional | 16.32 | 12.28 | 14.30 |
| Across Groups | 17.02 | 12.81 | |

The results of the analysis of covariance for the science sub-test appear in Table 5, while the adjusted means estimating the effects in the model appear in Table 6. The *F*=8.15 (p<.01) for the Group by Cognitive Level interaction (GROUP*COGLEVS) supports the suspected differential effect of IMaST on science *Knowing* compared to science *Processes*. The adjusted means in Table 6 estimate that effect. While the IMaST group performed better in science *Process* than science *Knowing* (18.09-17.31=.78), that same comparison (15.83-16.39= -.56) indicates a slightly opposite effect for the Traditional group. In addition, the F-value for the Group effect was 14.98 (p<.001), which indicates an overall difference between the groups across sub-tests. That difference is estimated by the adjusted means of 17.7 for the IMaST group and 16.11 for the Traditional group in Table 6. The IMaST group appeared to perform better on the science TIMSS than did their Traditional peers, especially on the science *Processes* sub-scale.

**Table 5**
*Analysis of Covariance Between Groups and Cognitive Levels for Science*

| Source | *df* | Sum of Squares | Mean Squares | *F* | *p* |
|---|---|---|---|---|---|
| GROUP | 1 | 563.38 | 563.38 | 14.98 | 0.0001 |
| SCPRE | 1 | 559.81 | 559.81 | 14.89 | 0.0001 |
| SUB (GROUP) | 517 | 19367.12 | 37.46 | | |
| | | | | | |
| COGLEVS | 1 | 6.35 | 6.35 | 0.46 | 0.4959 |
| GROUP*COGLEVS | 1 | 111.37 | 111.37 | 8.15 | 0.0045 |
| CogLEV*SUB (GRP) | 516 | 7053.14 | 13.67 | | |
| Total | 1037 | 53732.00 | | | |

*Note*. Number of observations in data set = 1078. Due to missing values, only 1038 observations were used in this analysis.

**Table 6**
*Table of Adjusted or Least Square Means for Science by Cognitive Level*

| Group | Knowing Science | Science Process | Across Cognitive Levels |
|---|---|---|---|
| IMaST | 17.31 | 18.09 | 17.70 |
| Traditional | 16.39 | 15.83 | 16.11 |
| Across Groups | 16.85 | 16.96 | |

The aforementioned sub-tests for mathematics and science were constructed from items found in the released item sets. Background information about TIMSS and a complete list of released items and can be found at: http://nces.ed.gov/timss/timss95/resources.asp.

Project staff gathered further indications of student achievement at individual sites. One example of this was student work and results from end of module assessments. These items significantly influenced the improvements made to subsequent editions of the curriculum. Student performance data have been quite encouraging. Efforts are now being made to utilize these data when marketing the IMaST materials.

*5. What are the professional development implications of adopting integrated materials?*

Data gathered with respect to change in teacher practice is qualitative in nature. Site visits were structured so that Project staff could observe whether teachers followed the IMaST implementation principles (Table 7).

These observations revealed that becoming a constructivist teacher was more difficult for some teachers than for others, and that it is an ongoing process. Most IMaST teachers prided themselves in knowing the subject matter in their discipline well. They found satisfaction in imparting their knowledge to others. They initially found it inefficient to have students discover knowledge through exploration and then apply it to a practical situation. This usually called for the development of increased classroom management skills and Socratic questioning skills. Over time, however, teachers began to realize that their former method of instruction only *seemed* efficient, and that students were able to retain and transfer knowledge more readily if engaged in contextual, concept-building processes with opportunities to connect new knowledge to previous understanding. Information related to teacher practice had some impact on revisions of student materials, but it had a major impact on revisions in the teachers' edition.

**Table 7**
*IMaST Implementation Principles*

| Principle | Explanation |
|---|---|
| Full collaboration | All pertinent members of the system, including central administrators, building administrators, teachers, and other stakeholders are a part of the learning improvement process. |
| Reflective actions | The school improvement process: (a) engages teachers in frequent, continuous, and increasingly concrete talk about teaching practice; (b) encourages teachers and administrators to observe and provide feedback to each other; and (c) encourages teachers and administrators to plan, design, and evaluate teaching materials and practices together. |
| External support | Individuals external to the system provide appropriate instruction and support, thereby becoming part of the systemic change process. Consultants acting as external change agents support systemic change by providing awareness level information, training on specific aspects of a program, assisting in designing and implementing a system for change, and playing a support role to leaders of the change. |
| Continuing process | The process is designed and implemented by the district or school, maintained throughout a significant period of time, and is modified as a result of feedback on results of the process. |

| | |
|---|---|
| Program focus | The process deals with curriculum, instruction, assessment, and the adequate support to maintain the program, including staff development, materials, and consultants. |
| Problem solving | The process is problem solving that focuses on improvement-of-instruction rather than compliance with rules and regulations. |
| Teacher is key | The teacher is the unit of change. Each teacher must develop his or her beliefs, knowledge, and skills for teaching. |

Strategies for overcoming barriers to implementation were addressed during training, in the instructional materials, and through the IMaST web site (http://www.ilstu.edu/depts/cemast). Project staff observed a reduction in the number and intensity of implementation barriers as a result of these efforts.

During the first five years of IMaST development, it was evident that most administrators were using IMaST materials to promote school reform. This included changes in the curriculum as well as reform in teaching practice. In 1997, however, two field-test sites were selected in states (Louisiana and New Mexico) that had had NSF State Systemic Reform projects. It soon became apparent that the IMaST curriculum was not only viewed as a catalyst for reform, but could also become a curriculum for schools that have undergone reform. Teachers from these states who engaged in the one-week summer inservice workshop were better prepared to initiate the IMaST curriculum in their school the following fall. This observation indicates that for successful implementation all teachers need extensive, concentrated inservice (50+ hours) training with ongoing support. Administrative support has proven to be essential to the long-term success of the IMaST curriculum.

The most successful professional development activity was for Project staff to initially model teaching practice expected of IMaST teachers and engage the teachers in the learning process in much the same way their students would experience it. These teachers were then provided with opportunities to practice teaching various portions of the IMaST curriculum in a constructivist manner. This practice was followed by a reflective session where they analyzed their own performance and discovered for themselves ways they might have improved their own teaching. The most successful teaching teams used this same "reflective" process throughout the school year.

*6. What strategies work for gaining community support and adoption of the materials?*

When a program that requires extensive reform, as IMaST does, is implemented in a school setting, it is essential that parents be made aware of the program goals, the unique characteristics, the unavoidable problems with pilot- and field-test versions of material, the expectations for students, and a mechanism whereby they can provide input into the assessment/improvement process. Most of the schools implementing IMaST initially provided written information to the parents and also held an informational meeting. The project provided the schools with a description of the curriculum and a brochure especially designed for parents. Most schools provided parents and their children an opportunity to choose whether they would like to be in the IMaST program. Those who chose to be in the program were invited to a session where they actually experienced one or more of the activities in the program. In this way, the parents experienced first-hand the same kind of anxieties, frustrations, as well as the enthusiasm their children experienced when they became engaged in the learning process.

The curriculum was tested in urban schools where resources were limited. This was the only way that we could ensure suitability for a broad range of students in a variety of situations. It was also implemented in schools where it was the only middle school math/science program in use. In sites where teachers had undergone staff development, there were not problems with community support. However, in one site where teachers were not provided necessary staff development, community support was not forthcoming and the program was not sustained.

One of the Project's goals was widespread adoption. The Project reached this goal where "lighthouse" schools were selected as field-test sites. Surrounding schools wanting to emulate the lighthouse school in their area have also adopted the program.

*7. How can innovative curricula negotiate the local or state curriculum adoption procedures?*

The adoption of IMaST materials depends greatly on the state or local policies concerning the adoption process. For example, in some states an integrated curriculum has to be approved as an exemplary, innovative curriculum before it can be widely used within the state. Additionally, some local adoption policies create the need to request an exception. Many districts have a rotation schedule whereby math adopts curriculum materials (textbooks) one year, science another year, and so on, and this rotation is repeated every five to seven years. In situations like this, school district personnel had to request an exception to standard policy. Since commercial editions of the IMaST materials are becoming available, more attention will be given to the development of strategies for supporting schools that would like to consider adopting the IMaST program.

*8. What articulation issues have arisen relative to students entering classes using the materials and for those moving to the next grade level?*

Site visit observations and teacher feedback indicate that students readily adapt to hands-on, experiential, contextual learning. In a few cases, however, it was reported that students who had been extremely successful in a traditional education program, where they were told exactly what to memorize and were given "the right answers," were initially frustrated with the IMaST program. For example, they were not accustomed to a teacher who responded to their questions with a question, rather than an answer. Moreover, the possibility of more than one answer being correct was hard for them to understand. Although rare, it has been noted that, on occasion, a student who had a record of straight As earned the first B in his academic career. In this case, the teacher was encouraged to immediately communicate with the parents to indicate an awareness of the situation and the high potential for improvement to occur. In every documented situation, students who fit into this category were able to earn an "A" by the second grading period.

There were a few minor articulation problems for students moving into or from the IMaST program. A greater concern was the articulation from IMaST in the middle school to traditional high school mathematics and science. Most attention in this regard was paid to articulation in mathematics. In some of the districts that implemented IMaST, the best mathematics students are given the opportunity to take algebra in the eighth grade. Although eighth grade IMaST includes geometry and discrete mathematics objectives, there has been no evidence to suggest that IMaST completers are disadvantaged when they enter high school. On the contrary, a study conducted by Sandall (1997) quotes an IMaST completer as a high school student saying "I think we are ahead of others in some cases. We had a broad range of activities, some at the eighth grade level, some more advanced. In some ways algebra is harder. We had some of it in IMaST but not a full year like the others. We had a lot of geometry." Furthermore, one of the middle schools in Michigan deliberately followed the progress of completers from their school who then attended two different high schools. The data gathered indicated that IMaST students earned a higher GPA than other graduates from their middle school.

## Summary

The development and implementation of a standards-based, integrated mathematics, science, and technology curriculum is fraught with many challenges, but these are balanced by strong indicators showing student benefits. Curriculum developers routinely acknowledge the complexity of developing a standards-based course for one discipline. This complexity is increased by a factor of at least three when one develops an integrated course for three disciplines. Three sets of standards need to be considered to provide the direction. Since few professionals have the background to use more than one set of standards, the development process requires the collaboration of representatives from all three disciplines. Not surprisingly, turf issues can hinder the development process.

There are, however, ways to reduce the complexity of developing integrated programs. For example, all three disciplines in the IMaST program have standards that relate to measurement, problem solving, and communication. The use of a common curriculum format, a common problem solving model, and assessment procedures not only promotes integration, but it helps students make connections among the disciplines.

The implementation of an integrated curriculum is also a demanding process. Unless one teacher is responsible for the whole curriculum, two or more teachers must work together. This requires common planning time, and time is a precious commodity in middle schools. Other issues that affect implementation are scheduling, classroom space (including storage), the teachers' classroom management skills, and the ability of teachers to make the transition to constructivist pedagogy.

The extra effort it takes to develop and implement an integrated mathematics, science, and technology curriculum produces significant benefits. Students are able to link concepts learned in one discipline to related concepts in another. Students are more motivated to learn because they not only see the discipline connections, but they see the connections with real life situations. Of lesser importance, but significant to administrators and parents, is the fact that students do score higher on standardized tests in mathematics and science.

## Conclusions

Based on the evidence collected during the development of the IMaST program, the following conclusions are offered:

1. The development of a standards-based, integrated mathematics, science, and technology curriculum is a

challenging task. It requires the development of a curriculum framework, the involvement of classroom teachers and expert reviewers, field-testing with constant feedback, frequent revision, and a consistent process to assure that standards are being met.

2. To assure that a curriculum is standards-based, developers must begin with standards as the curriculum framework. This framework must be developed and constantly checked against the standards during each stage of development. An external review near the end of the development process is recommended to assure that the standards from each discipline have been incorporated into the materials.
3. There are significant barriers to the implementation of integrated materials. These include lack of planning time, facility inadequacies, and individual and statewide assessment issues. These barriers are reduced through strong, district-wide administrative support.
4. The IMaST program has the potential for causing students to score as well as or better than students in traditional programs on assessments such as TIMSS. Some of this increase may be due to the IMaST curriculum.
5. The implementation of IMaST requires a well-planned professional development program including an intervention of at least one week of full-time inservice training, plus ongoing support.
6. Administrative and community support is essential for the implementation and sustainability of an integrated program.
7. State and local policies not only impact the development process, but also the sustainability of the curriculum.
8. Many schools do not have enough technology teachers for all students to have a year-long technology experience at each grade level. This is particularly true at the sixth grade level. In order for students to make progress toward meeting the *Standards for Technological Literacy*, it is essential for math and science teachers to provide instructional support. In this case, professional development in technology for math and science teachers is required.
9. Some IMaST students are frustrated when they initially enter an integrated, hands-on program, but they soon adjust to the active learning process. Follow-up studies show that students make successful transitions in mathematics and science courses when they matriculate to high school.

## Recommendations for Further Research

Based on our experiences with the IMaST Project, we have identified a number of issues that warrant further research and development. For example, in this project student outcomes were measured primarily through instruments that focus on mathematics and science. An assessment tool needs to be developed to measure students' technological literacy, so that gains in this critical area can also be studied. We further recommend investment in a long-term companion study to determine the impacts of implementing the IMaST program in a school over an extended period. A model professional development program needs to be developed for technology teachers to learn mathematics and science content. Likewise, programs are needed for mathematics and science teachers to learn about technology and the pedagogical strategies commonly used in technology classrooms. Finally, curriculum projects that focus on the middle grades must recognize that teaching teams are made of language arts, social studies, mathematics, science, and, occasionally, technology teachers. To support these teams, we recommend development of a fully integrated language arts, social studies, mathematics, science, and technology curriculum.

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*Authors' Note*: This manuscript is based upon work supported by the National Science Foundation under Grant No. 9819002. The federal government has certain rights to this material. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

## Appendix

*The IMaST Modules, Module Objectives, and Key Concepts by Grade Level*

| Grade | Module Title | Module Objective | Key Concepts |
|---|---|---|---|
| 6 | *Tools for Learning* | Use cognitive (problem-solving and processing (measuring, shaping, etc.) tools to discover mathematical, scientific, and technological patterns | problem solving, teaming, identifying patterns, designing, communicating |
| 6 | *Patterns Below* Us | Analyze patterns in geometry. | number sense, geosphere, raw materials |
| 6 | *Patterns Around Us* | Analyze conditions of water through data display. | water circulation, data display, water pollution, water conservation, universal solvent |
| 6 | *Patterns of Weather* | Use number relationships to identify and predict patterns of change in climate and weather. | technological development, number relationships, climate and weather instrumentation |
| 6 | *Patterns of Mobility* | Describe the structure and function of numbers, the movement of living organisms, and transportation devices as they relate to mobility. | number theory, mobility, classification |
| 6 | *Patterns Above Us* | Use appropriate methods to investigate, measure, and represent relationships among the atmosphere, natural activities, and technological activities on Earth. | fractions, atmosphere, air pollution |
| 6 | *Patterns Within Us* | Compare genetic patterns that determine traits. | genetic engineering, probability, heredity, reproduction |
| 7 | *The Body Works* | Identify relevant information and then make educated decisions to improve your health. | energy, pre-algebra, exercise and nutrition |
| | *Shaping Our* | Conduct an analysis of the effects that time, movement, | geometry, adaptation, |

| | | | |
|---|---|---|---|
| 7 | *World* | and geometry have on the natural and human-made world. | transportation |
| 7 | *Living on the Edge* | Analyze the relationships within and between communities of living organisms. | Ecosystems, agriculture, data analysis |
| 7 | *Manufacturing* | Design, produce, and evaluate a product that meets a need, demonstrates effective use of materials, generates little waste, and is affordable. | quality, efficiency, design, production, materials |
| 7 | *Forecasting* | Develop, graph, and solve linear equations verbally, tabularly, graphically, and symbolically to make predictions. | patterns, slope, prediction |
| 8 | *Animal Habitats* | Plan a balanced ecosystem that considers the impact of the physical environment and the relationship between the environment and the behavior of animals. | population, behavior, ecosystems, measurement |
| 8 | *Human Settlements* | Design a sustainable human settlement that considers the impact of environment, the relationship of man to his surroundings, human behavior, and the natural environment. | number sense, geosphere, raw materials |
| 8 | *Systems* | Use a systems model to analyze, design, and model natural and human-made systems. | systems model, relationships, variables |
| 8 | *Communication Pathways* | Analyze, design, and construct communication systems. | message, device, medium, efficiency |

Satchwell (resatch@ilstu.edu) is the Project Coordinator for the Integrated Mathematics, Science, and Technology Project and Loepp (flloep@ilstu.edu) is a Distinguished Professor and Director of the Center for Mathematics, Science, and Technology at Illinois State University in Normal, Illinois.