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The Effect of Mathematics Instruction in an Integrated Curriculum: Achievement of Seventh Grade IMaST Students[1]

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Abstract: The results of an achievement study in mathematics conducted using the Integrated Mathematics, Science, and Technology (IMaST) curriculum are discussed. The study used both standardized test scores and student-constructed-response items to measure students' mathematics achievement. The study shows that the student achievement results are consistent with the different methods of instruction used in traditional curriculum versus more problem-based curricula. The traditional, comparison group performed significantly better in situations where memorization or procedural knowledge were being measured, and the experimental group performed significantly better on open-ended problem-solving tasks. There was no significant difference in the computational performance of the two groups.

Introduction

For years, fragmentation of the curriculum has been a stumbling block for students, especially when they are later expected to combine their knowledge in new situations (Jacobs, 1989). Educational standards for mathematics and science recommend connecting material to other disciplines and to the "real world" (NRC, 1996; NCTM, 2000). Additionally, as the middle school concept continues to evolve, many have argued that the curriculum should have more subject matter integration (Bean, 1991; Berla, Henderson, & Kerewsky, 1989; George, Stevenson, Thomason, & Beane, 1992). This would potentially allow students to see both the connections between and complementary applications of concepts and principles across disciplinary lines. Roth (1993) specifically discussed the need to develop a set of problem-centered learning activities which integrate mathematics and science and study the results of the use of such materials. While several studies involving the impact of integration on students were done during the 1970's and 80's (e.g.,

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Friend, 1985; Shann, 1977), recent studies focus on teachers and implementation issues related to integrated curriculum (e.g., Venville, Wallace, Rennie, & Malone, 1998; Lehman, 1994; Lehman & McDonald, 1988). As a result, questions regarding the impact of the use of integrated curriculum materials persist.

The Problem

As integrated curriculum or interdisciplinary study increases, so does the discomfort of many mathematicians and mathematics teachers. The question of "Where's the math?" has surfaced on more than one occasion, and with more than one meaning. In one scenario, the question simply means "Why has mathematics not been included in the integrated units of study?" While in another related scenario, it may refer to the lack of breadth of mathematics topics being included. For instance, data and statistics seem to be the only mathematics integrated in many cases. This leads many mathematics teachers to wonder what happened to the other mathematics topics. The problems represented in these scenarios are relatively easy to solve. It requires mathematics teachers, or mathematics specialists, to be actively involved in the writing and design of the integrated units of study. Additionally, breadth can be assured by detailing how the materials meet all of the content criteria incorporated in the NCTM *Principles and Standards* (2000). The final meaning of this question can often be restated as: "Where are the worksheets and drill and practice problems which are so prevalent in the traditional mathematics curriculum?" These are the thoughts of many parents and teachers when faced with innovative mathematics programs such as those developed through the NSF-funded Instructional Materials Development grants. Many of these programs revolve around mathematics being taught in context rather than as isolated concepts and ideas. These programs may appear, at first glance, to be lacking in mathematics content when in truth they are simply lacking in isolated drill and practice. In-depth examination, and experience with the materials can change these initial impressions. Unfortunately, many individuals never get past the first glance and never complete a more in-depth examination. Individuals need to be strongly encouraged to pursue a more thorough examination of materials, since this analysis is not routinely done.

Perhaps the most important underlying question is "Can students who learn mathematics in a program without all the drill and practice worksheets still achieve the same level of mathematical understanding and skill as students who are taught mathematics in a more traditional approach?" This question calls for research on the impact of use of these types of programs on student achievement. The study reported here provides evidence regarding the impact of mathematics studied in this non-traditional manner. This study was based on the use of the Integrated Mathematics, Science, and Technology (IMaST) NSF-funded 7^{th} grade curriculum project, a project which has addressed many of the problems associated with the question "Where's the math?" including the issues of student achievement.

The IMaST Curriculum Project Background

The IMaST program consists of a complete mathematics, science, and technology curriculum for seventh-grade students. The activities integrate concepts and processes from all three disciplines. It emphasizes connections through a problem-solving approach requiring students to identify and use patterns to form conjectures, and to describe relationships while working together to resolve context-rich problems. The year-long curriculum is divided into six theme-based modules. Each module was developed using the concepts and ideas typically covered in more traditional seventh-grade mathematics, science, and technology curricula, as well as additional concepts which meet new educational standards.

The program was built around a learning cycle format (Marek & Cavallo, 1997) where students explore situations, discuss their findings to develop a concept or idea, apply the idea in a similar setting or context, and finally expand the idea to new settings and more global contexts. In this way, the IMaST program has adopted a constructivist (Goldin, 1990) approach to learning. Constructivist curricula present situations where students examine their own ideas in relation to new experiences which then encourage them to expand their understandings.

The curriculum is designed to be taught by three teachers, one from each discipline, teamed together with a group of students for a total of 120 minutes per school day. This time can be a single flexible block, or divided into three 40 minute periods. The content is carefully structured to help teachers work cooperatively, and to inter-relate ideas across content areas. Students are often placed in small groups where they are required to demonstrate behaviors such as shared decision making and supporting other's ideas. Students do not complete worksheets of exercises but are instead given problems to solve. The students are provided with journal sheets to record information regarding the solution process while keeping a record of their work. There is no isolated mathematical drill and practice involved in this program. Any computation or practice students receive is in context of solving problems related to the theme of the module.

Authentic assessments are used as a basis for grading, and rubrics are provided for teachers in order to aid in judging student proficiency. Assessments of this type are available for each activity as well as for use at the end of each module. While individual activity assessments are typically related to a single subject, the end of the module assessment is an integrated assessment, requiring demonstration of concepts from all areas of the curriculum. In keeping with this philosophy and format, students do not take traditional single subject unit/module exams as part of the program.

Clearly, IMaST represents a non-traditional approach to the instruction and assessment of mathematics at the seventh-grade level. As such, it represents an ideal curriculum to study and help address questions related to the mathematics achievement of students in non-traditional curricula versus those in a traditional program of study.

The Study

The research reported here was undertaken to help answer the following research question and its related components.

How does the overall mathematics achievement of students who participate in seventh-grade IMaST compare to students who participate in a more traditional seventh-grade mathematics program?

a) How do their problem-solving skills compare?
b) How do their instrumental and relational knowledge compare?
c) How do their computational skills compare?

Participants

Five schools who were using the IMaST materials for all or part of their seventh-grade student enrollment agreed to participate in this achievement study. These schools included two suburban middle schools, one urban school and two rural schools from three states in the Midwest. The demographics of these schools were diverse, with two of the schools having a high minority population, including one school where approximately 90% of the population was Native American. The other three schools had a low percentage of minority students.

Three of the schools had both IMaST and a traditional mathematics curriculum being taught at the seventh-grade level, including one of the high minority schools. The sites where both traditional seventh-grade mathematics classes and IMaST classes were taught provided the comparison groups for the study. The students at these sites were not randomly assigned to IMaST or traditional mathematics classes. The parents and students were provided with information about the IMaST project and the traditional mathematics program, and enrollment was based on parental and student choice. The remaining two sites had all their seventh-grade students enrolled in IMaST, so no comparison group was available and students and parents were not offered the option of IMaST or traditional instruction. This lack of random assignment is reflective of the realities of conducting research in most public schools. An additional limitation of this study came from the high mobility rate of students at several of these participating schools. The number of students who had completed the full achievement study was reduced by nearly 50% from the start of the study to its end, due in part to the mobility of the student populations. While this attrition rate caused concerns, it was not avoidable. Since the remaining sample size was still large enough to allow for analysis of matched pre- and post-tests with reasonable-sized groups, the findings are still worthwhile.

Instruments

Each participating school was asked to administer the mathematics sections of the Stanford Achievement Test Series. These scores were recorded in terms of the grade placement levels for the students, where the grade placement levels were determined according to the Grade 7, National Norms for Form K, Advanced Level 1 (Harcourt Brace Jovanovich, 1992). The Stanford Tests were administered in both early fall of the school year and again in late spring of the same school year. These tests were given in an attempt to establish the growth of students in both IMaST and traditional classes in the schools relative to traditionally held measures of student competence. As such, the administered portions provided an overall mathematics score, and sub-test scores on concepts of number, computation and applications. The concepts of number section of this test has been cited as extremely procedural (Romberg, Wilson, Khaketla, & Chavarria, 1992), and as such was used in this study as a measure of instrumental understanding, rather than relational understanding as described by Skemp (1987).

In addition to the Stanford Achievement Test in mathematics, students in the IMaST and comparison classes were asked to complete a series of three open-ended student-constructed-response items in mathematics in late spring. While post-only testing is not ideal, the fall testing schedule in schools was already crowded, and it was thought to be counterproductive to instruction to impose additional days of testing at the beginning of the school year. The items used were selected from released items from the 1992 National Assessment of Educational Progress (NAEP) mathematics test. The three items selected were chosen because they were representative of non-traditional, student-constructed response items measuring the full gamut of student mathematics expectations, including understanding of number and operations, combinatorial reasoning, geometry, measurement, patterns, and functions. The three items used, and the general scoring rubric can be found in Appendix A. Each of these items was scored using the 6-point rubric scale adopted for scoring the same items at the national and trial-state levels in the 1992 NAEP assessment (Dossey, 1993). To insure reliability of scoring, two scorers graded each student’s test, and any items with different scores were discussed to reach consensus.

Analysis

Scores from the fall Stanford Achievement Tests were used as baseline scores for comparison for all spring measures. Since there was not random placement of students into the IMaST program at any of the schools, a t-test of means on fall scores was used to determine if significant differences existed between the IMaST and the comparison group in the fall. Based on the finding of between group differences in some measures of mathematics achievement in the fall, the decision was made to use an analysis of covariance on the standardized test results. Further, the schools involved in the study were interested in the differential gains that students in each group may achieve. As a result, the decision to use gain-score analysis was made. While the gain-score analysis may involve some controversy, the external evaluator for the project and the project statistician decided that using a combination of gain-score analysis and an analysis of covariance would produce the most conservative estimates of potential differences, as well as further protect against differential gain rates that might be predicted based on any significant differences existing in fall test data between the IMaST and comparison students. In this analysis, the Stanford Achievement Test score gains from fall to spring were used as a dependent measure, with the type of class participation as a grouping factor, and the fall test scores were used as the covariate. Other variables, such as school or individual teacher, were not included as a grouping factor, due to the small sample size these groups would generate. Additionally, it was believed that the teacher or classroom variable would be difficult to isolate, since each IMaST student had multiple multidisciplinary teachers during the study and mathematics was taught or reinforced by virtually all of these teachers.

Since the free-response items were administered only in the spring, there was not a gain score to analyze, and there was not a pretest score on the same items to use as a covariate. Instead, correlations were calculated between the scores on these items and the fall Stanford Achievement Test and subtest results, and the most highly correlated score was used as the covariate. In this way, the most closely related measure available was used to adjust for differences in the IMaST and comparison group.

Results of the Study

Stanford Achievement Test

Students from the five participating schools were given the portions of the Stanford that resulted in a Total Mathematics score, a Concept of Number score, a Mathematics Computation score, and a Mathematics Application score. These sections of the examination were administered by their teachers and the results forwarded to National Computer Systems in Iowa City, Iowa, for scoring. The results were then evaluated according to the Advanced Level 1, national norms for the seventh grade.

As there was no random placement of students into the sections of the seventh grade in any of the schools, the data from the fall administration of the Stanford was used to determine if significant differences existed between the IMaST students and the comparison group students. A summary of the mean scores of each group and the results of the t-test comparing these means can be found in Table 1. Given that significant differences existed in some measures between the incoming fall scores for the students between the IMaST and comparison sections, the decision was made to use a gain-score analysis, based on grade placement levels, with their entering score in the corresponding area as a covariate.

Table 1
Mean Grade Level Scores for the Fall Stanford Achievement Tests by Group

	Mathematics Total	Concepts of Number	Computation	Applications
IMaST (n)	7.898 (141)	7.926 (152)	7.949 (142)	8.417 (151)
Comparison (n)	9.009 (54)	9.972 (56)	8.112 (60)	8.227 (57)
Results of t-test	$F=6.87$ $p < 0.01$	$F = 23.09$ $p < 0.001$	$F = 0.13$ $p > 0.05$	$F = 0.16$ $p > 0.05$

Total Mathematics Testing
The Total Mathematics gain scores for each group were first calculated. The mean grade placement gain scores for the IMaST students was 0.208 grades ($n = 141$) and for the comparison group -0.090 grades ($n = 54$). These scores indicate that the comparison group actually had a mean score decrease in the spring compared to the fall testing. However, the analysis used the same set of norms, so the grade level scores should be directly comparable. Since the fall testing data indicated there were significant differences in the performance of the IMaST and comparisons that could not be accounted for by chance alone, an Analysis of Covariance (ANCOVA) was used to examine differential gains. The grade placement gain score was used as the dependent measure, the type of class as the grouping factor, and the fall Total Mathematics Score grade placement was used as the covariate. The results of this analysis are shown in Table 2. Based on this analysis, no significant differences were found between the gain in Total Mathematics scores of the IMaST students and the comparison group students.

Table 2
ANCOVA for Grade Placement Gains for Total Mathematics Score

Source	SS	df	Mean-Square	F-Ratio	p
Type of Class	3.345	1	3.345	0.90	0.343
Fall Total Math	97.719	1	97.719	26.39	0.000
Error	711.087	192	3.704		

Mathematics Computation Testing

While the fall testing showed no significant differences in computation between the IMaST and comparison groups, it was decided that for consistency the same analysis of covariance would be calculated on all measures. So the mean grade placement gain scores for computation were first determined. The mean grade placement gain scores for the IMaST students was 0.354 grades (n = 145) and for the comparison students -0.373 grades (n = 57). Again the comparison group spring scores were lower than their initial fall test scores. The results of the analysis of covariance for the computation gains are shown in Table 3. While the mean gains scores appear to favor the IMaST group, the analysis of covariance indicates there were not significant differences, at the p = 0.05 level, in the computational gain scores between the IMaST and comparison groups when the incoming computational scores are factored out.

Table 3

ANCOVA for Grade Placement Gains for Math. Computation Score

Source	Adj. SS	df	Mean-Square	F-Ratio	p
Type of Class	20.26	1	20.26	3.23	0.074
Fall Math Comp	268.76	1	268.76	42.79	0.000
Error	1250.03	199	6.28		

Concepts of Number Testing

The mean gain scores for concepts of number showed that students in the comparison sections (n = 58) gained 1.30 grade placements in concepts of number test while students in IMaST sections (n = 150) *dropped* 0.03 grade placements. According to the fall testing data the comparison group scored significantly better in concepts and procedures than the IMaST group at the start of the school year. So, the analysis of covariance test was run to see if the fall difference accounted for the difference in gain scores. The results of this analysis are found in Table 4. While the fall concept of number test data was judged to have controlled a significant proportion of the gain scores for concepts of number test, they did not account for all the difference. The comparison group still had significantly higher gains in the concepts of number test, at the p = 0.001 level, even after controlling for the fall scores.

Table 4

ANCOVA for Grade Placement Gains for Concept of Numbers

Source	Adj. SS	df	Mean-Square	F-Ratio	p
Type of Class	73.053	1	73.053	21.15	0.000
Fall Number Concept	98.392	1	98.392	28.49	0.000
Error	708.074	205	3.454		

Mathematics Applications Testing

The fall test scores for the IMaST and the comparison group were not significantly different. However, to maintain consistency in data analysis, an analysis of covariance on gain scores in mathematical applications was still used The actual mean gain score in mathematical applications was 0.266 grades for the IMaST group (n = 148) compared to a *decrease of* 0.199 grades for the comparison group (n = 58). The results of the analysis of covariance are shown in Table 5. After controlling for the fall mathematics applications scores, no significant differences were found in the gain scores between the two groups.

Table 5

ANCOVA for Grade Placement Gain for Mathematics Applications

Source	Adj. SS	df	Mean-Square	F-Ratio	p
Type of Class	8.95	1	8.95	1.60	0.207
Fall Math Appls	206.25	1	206.25	36.94	0.000
Error	1133.34	203	5.58		

Student-Constructed Response Mathematics Examination

The mean of the Total Student-Constructed Response scores in spring for the IMaST group was 6.83 points (n = 127) and for the comparison group was 4.95 points (n = 56). As the previous analyses indicated differences existed across the IMaST and comparison sections in the fall, the analyses of the student-constructed response data again suggested the appropriate use of an analysis of covariance approach. Since there were no fall scores on the student-constructed-response items, the fall Total Mathematics score from the Stanford Achievement tests was used as the covariate. This choice was made due to the relatively high correlation between this score and the spring total score for the student constructed response items. It also allowed for keeping more students in the analysis due to some differential completion of the open-ended items and achievement tests. The results of this analysis are shown in Table 6.

Table 6

ANCOVA for Total Student Constructed Response Math Score

Source	Adj. SS	df	Mean-Square	F-Ratio	p
Type of Class	134.87	1	134.87	25.38	0.000
Fall Stanford Total Math Score	347.02	1	347.02	65.31	0.000
Error	956.34	180	5.31		

The results of the ANCOVA suggest that significant differences, at the 0.001 level, exist between the Total Student-Constructed-Response scores for students in the

IMaST and comparison sections, even after controlling for the fall Total Mathematics scores.

Since each of the three student-constructed-response items involved different mathematical concepts, a problem-by-problem analysis was used to examine if one specific area of content may have contributed more to the overall differences in student performance. A problem-by-problem analysis of the student-constructed item scores, using the same analysis of covariance methods, illustrated that a significant difference ($p = 0.05$) occurred across all three open-ended problems. Table 7 provides a summary of the findings across problems for the two groups.

Table 7
Individual Student-constructed Response Problem Means by Group

	Sports Camp	Radio Tower	Dots
IMaST	3.04	1.58	2.24
Comparison	2.26	1.15	1.14

Discussion of Results

The results show what one may expect from any curriculum: that the students' growth is dependent, to some degree, on the emphasis of the instructional strategies being utilized. While the comparison students were involved in classes of a traditional nature with heavy emphasis on computation, and isolated mathematical concepts and procedures, the IMaST students were exposed to virtually no drill and practice in terms of computation or utilization of isolated concepts and procedures. Instead the IMaST classes were involved in contextual problem solving, and derivation of conceptual understanding through contextual explorations and discussions. With extremely different instructional approaches and emphasis, one would expect to find differences in student achievement. Perhaps surprisingly, there were no significant differences in the overall mathematics achievement of these students, as measured by the mathematics composite score of the Stanford Test. This test, as with most standardized tests of its nature, is designed to measure achievement according to the students' ability to perform mathematical calculations in isolated settings. While it contains subsections entitled Computation, Concepts of Number, and Applications, its items are almost all procedural in nature, with very few conceptual questions, and virtually no problem solving (Romberg, Wilson, Khaketla, & Chavarria, 1992). As a result one would expect it to be a valid instrument for assessing students' instrumental understanding of mathematics (Skemp, 1987) which is the focus of a more traditional mathematics program. Additionally one would expect it to provide less valid information about student achievement in areas Skemp would term relational understanding of mathematics, which are more typical of an NCTM standards-based curriculum.

With these test limitations in mind, it was interesting to note that the computation of students in IMaST did not suffer. While the IMaST students made slight gains in this area, and comparison students actually decreased their scores, there were no significant differences between the groups in change in computational facility.

The Concepts of Numbers test produced the results which would be the most disturbing to individuals or school districts considering adopting programs such as IMaST. Here the students in a traditional program did out-perform students in the IMaST program. A natural concern is that IMaST students do not understand mathematical concepts. However, according to Romberg, et al.'s (1992) findings, nearly all of the items in this test are really procedural in nature, with very few items reflecting conceptual understanding. As a result, without any context to aid the IMaST students in making sense of the situation, and without the practice on isolated skills, the IMaST students may be expected to be at a disadvantage on procedural types of items. Thus, due to the nature of the test, these results should not be interpreted as meaning the students are weak in conceptual or relational understanding.

In the Application section, one might expect to see favorable results for the experimental group since one would expect it to be more focused on the use of the mathematical knowledge. The IMaST students did make slight gains in this area while comparison students experienced slight drops in scores. While the differences were not significant, we must also remember the test has been criticized as being more computational and procedural than problem solving in nature (Romberg, et al., 1992).

Using Skemp's (1987) terminology, both the Concepts of Number and the Application sections would be more reflective of a student's instrumental understanding, than it is of their relational understanding. If we are to measure more relational understanding, we must ask students to solve problems that use multiple concepts and ask them to relate ideas to one another in a meaningful way.

Sources in recent years have pointed to the need for open-ended problems and test items to truly measure a students mathematical understanding (Romberg, et al., 1992) as outlined by the NCTM *Standards* (1989). Many assessments are now being created in an attempt to address this need. This study used three such open-ended problems which were items released by NAEP in 1992. The results of this study with respect to these open-ended items are perhaps the most telling about the students' relational understanding. The IMaST students out-performed the comparison group at a significant level. In fact, while the IMaST students were typically viewed as "lower ability" than the comparison students, their total scores as well as their scores for each item on the open-ended problems were consistently significantly higher. This result is particularly interesting since these are problems that Skemp would classify as involving relational understanding, and required more thinking, reasoning, and communication. One would think that students who have less instrumental understanding would struggle with these relational tasks, but such is not the case.

While issues around testing always exist, there are other considerations which combine to make the results of this study more promising for the future of IMaST and students in similar programs. First, this is a new curriculum which involves a very different mode of instruction for most teachers. Meanwhile, the teachers of the comparison group have been using the same materials and methods for a number of years. One might assume that as teachers became more familiar with the problem-solving, learning cycle approach to instruction utilized in IMaST, the results their students achieve would be even greater. Additionally, these results are based on the impact of one year of instruction. The students typically take the first quarter to become comfortable working in the non-traditional setting and format of the IMaST classroom. The results of multiple years of exposure to a similar program of study should show even more dramatic results. Longitudinal studies are needed to provide information on the lasting effects of the program.

One limitation of this study is the lack of control for individual teacher differences and the impact IMaST may have on teachers of the comparison groups at the same school. For example, it is possible that either group at any school may simply have had a more effective teacher. It is also possible that discussions of activities and methods used with the IMaST group could impact the methods and activities used with the comparison group of students at the same school. Further studies need to be completed where comparison groups are isolated from the treatment group so cross-contamination is not possible. Additionally, larger scale studies are needed where analysis by individual teachers will result in large enough group sizes to make such analysis techniques feasible.

Implications

The manner in which we teach and present material, as well as the manner in which we assess understanding, make a difference as to what our students are able to do. The results of this study concur with findings of Shann (1977), Friend (1985), and Roth (1993): Students in interdisciplinary programs benefit from the experience of having mathematics and science inter-related on a daily basis. Friend looked at the positive impacts on students attitudes, while Shann and Roth also considered overall achievement. This study considered the impact on different components of mathematics achievement, to identify any strengths and weaknesses that students in an integrated program may develop.

These results point to the importance of teaching and assessing in a manner which reflects the desired outcomes. If we want our students to become more powerful problem solvers, we must teach in a manner which emphasizes and assesses problem solving.

If a middle school is considering moving toward a more integrated curriculum or an interdisciplinary approach to instruction, but is worried about the mathematics achievement of their students, the IMaST program can be a viable alternative. However, clear expectations and visions of instruction and assessment must be developed by the teachers, administrators, and parents of the students. If this is not done, inappropriate assessment methods may lead to the abandonment of promising practices and a return to teaching isolated skills and procedures over teaching for thinking and problem solving.

Recommendations for Further Research

The results reported here are based on a single school year in five schools. There are limitations in the study due to sample size (especially of the comparison group). There are also limitations based on the duration of the program. As a result the following additional research is recommended:

- continue to replicate this study with larger samples and using class as a unit of study.
- expand the study to include an item analysis of Concepts of Number section of the Stanford test.
- continue to monitor these students as they progress through the remainder of their school career after only a limited time exposure to IMaST.
- monitor students who complete a 2 or 3 year IMaST program for its immediate and lasting effects.
- study science and technology achievement as well as mathematics achievement in an integrated program.
- study attitudinal and affective issues related to the IMaST program.
- complete comparative achievement studies with other innovative Standards-based mathematics programs.

Summary

Overall, the evaluation results show that the use of the IMaST curriculum may foster the more investigative aspects of learning in students. The comparison group appears to excel in developing specific facts and definitions that must be committed to memory. That is, each approach tends to benefit the cognitive activities associated with the format and focus of the instruction. It is clear from the data that the approaches to mathematics, science, and technology offered by the IMaST program are not injurious to students' progress. Hence if a school is considering a move toward a more constructivist, integrated approach to learning, and trying to focus more on problem solving than on isolated skills, the school personnel might want to consider an integrated approach such as IMaST as an alternative to a more traditional program.

References

Bean, J. A. (1991). The middle school: The natural home of integrated curriculum. *Educational Leadership, 49* (2), 9-13.

Berla, N., Henderson, A. T., & Kerewsky, W. (1989). *The middle school years: A parents' handbook*. Columbia, MD: National Committee for Citizens in Education.

Dossey, J. (1993). *Results of the 1992 trial state assessment*. Washington, DC: National Center for Education Statistics.

Friend, H. (1985). The effect of science and mathematics integration on selected seventh grade students' attitudes towards achievement in science. *School Science and Mathematics, 85*(6), 453-461.

George, P. S., Stevenson, C., Thomason, J., & Beane, J. (1992). *The middle school years and beyond.* Alexandria, VA: Association for Supervision of Curriculum Development (ASCD).

Goldin, G. A. (1990). Epistemology, constructivism, and discovery learning in mathematics. In R. B. Davis, C. A. Maher, & N. Noddings (Eds.), *Journal for Research in Mathematics Education monograph #4: Constructivist views on the teaching and learning of mathematics*. pp 31-47. Reston, VA: National Council of Teachers of Mathematics.

Harcourt Brace Jovanovich. (1992). *Stanford achievement test series*. (Eighth Edition, Form K). San Antonio, TX: Author.

Jacobs, H. H. (1989). *Interdisciplinary curriculum: Design and implementation*. Alexandria, VA: Association for Supervision of Curriculum Development.

Lehman, J. R. (1994). Integrating science and mathematics: Perceptions of preservice and practicing elementary teachers. *School Science and Mathematics, 94*(2), 58-64.

Lehman, J. R., & McDonald, J. L. (1988). Teachers' perceptions of the integration of mathematics and science. *School Science and Mathematics, 88*(8),642-649.

Marek, E. A., & Cavallo, A. M. L. (1997). *The learning cycle: Elementary school science and beyond.* Portsmouth, NH: Heinemann.

National Council of Teachers of Mathematics. (2000). *Principles and standards for school mathematics*. Reston, VA: Author.

National Research Council. (1996). *National science education standards*. (NSES). Washington, DC: Author.

Romberg, T. A., Wilson, L., Khaketla, M., & Chavarria, S. (1992). Curriculum and test alignment. In T. A. Romberg (Ed.), *Mathematics assessment and evaluation: Imperatives for mathematics educators.* Albany, NY: State University of New York Press.

Roth, W. M. (1993). Problem-centered learning for the integration of mathematics and science in a constructivist laboratory. A case study. *School Science and Mathematics, 93*(3), 113-122.

Shann, M. H. (1977). Evaluation of an interdisciplinary, problem solving curriculum in elementary science and mathematics. *Science Education, 61*(4), 491-502.

Skemp, R. R. (1987). *Relational understanding and instrumental understanding: The psychology of learning mathematics.* Lawrence Erlbaum: Hillsdale, NJ.

Venville, G., Wallace, J., Rennie, L J., & Malone, J (1998). The integration of science, mathematics, and technology in a discipline-based culture. *School Science and Mathematics, 98*(6), 294-301.

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Appendix A

Student-Constructed Response Items
and their Associated Scoring Rubrics (Dossey, 1993)

The Sport Camp Problem

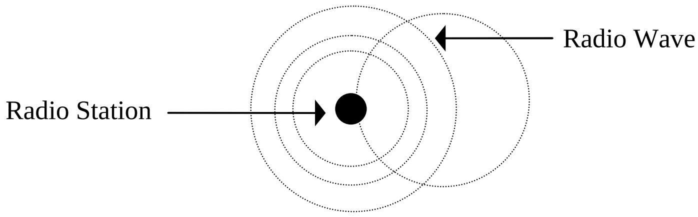
Treena won a 7-day scholarship worth $1000 to the Pro-Shot Basketball Camp. Round-trip travel expenses to the camp are $335 by air or $125 by train. At the camp she must choose between a week of individual instruction at $60 per day or a week of group instruction at $40 per day. Treena’s food and other expenses are fixed at $45 per day. If she does not spend any money other than the scholarship, what are all choices of travel and instruction plans that she could make? Explain your reasoning.

NAEP 6 point rubric for scoring:

0	No response
1	Incorrect - Student work is completely irrelevant or writes “I don’t know”
2	Minimal – (a) Student indicates one or more options only with no supporting evidence, or (b) student work contains major mathematical errors and/or flaws in reasoning.
3	Partial – The student (a) indicates one or more correct options; additional supporting work is present, but may contain some computational errors; or (b) demonstrates correct mathematics for one or two options, but does not indicate the options that are supported by his or her mathematics.
4	Satisfactory – The student (a) shows correct mathematical evidence that Treena has three options, but the supporting work is incomplete; or (b) shows correct mathematical evidence for two of Treena’s three options and the supporting evidence is clear and complete.
5	Extended – The correct solution indicates what the three possible options are and includes supporting work for each option.

The Radio Station Problem
Radio station KMAT in Math City is 200 miles from radio station KGEO in Geometry City. Highway 7, a straight road, connects the two cities.

KMAT broadcasts can be received up to 150 miles in all directions from the station, and KGEO broadcasts can be received up to 125 miles in all directions. Radio waves travel from each radio station through the air, as represented below.



Draw a diagram that shows the following:

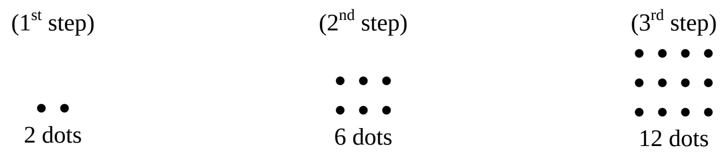
- Highway 7
- The location of the two radio stations
- The part of Highway 7 where both radio stations can be received

Be sure to label the distances along the highway and the length in miles of the part of the highway where both stations can be received.

NAEP 6 point rubric for scoring:

0	No response
1	Student work is completely irrelevant or writes “I don’t know”
2	Minimal - Diagram with only cities, Hwy. 7, and 200 miles labeled. Some but not all distances labeled. Does not recognize common broadcast area is a length along the highway.
3	Partial - Diagram with cities, Hwy. 7, and 200 miles labeled. Identifies common broadcast area along the highway. Two or more radio distances not labeled.
4	Satisfactory - Diagram with cities, Hwy. 7, and all distances labeled. But omits or incorrectly computes the length of the highway along which both stations can be received
5	Extended - An accurate well-labeled diagram (as described in the score 4 category), clearly indicating the portion of Hwy. 7 along which both radio stations can be received is 75 miles in length.

The Dots Problem
A pattern of dots is shown below. At each step, more dots are added to the pattern. The number of dots added at each step is enough to allow the pattern of dots to continue to grow in the manner shown. The pattern continues infinitely.



Marcy has to determine the number of dots in the 20th step, but doesn't want to draw all 20 pictures and then count the dots.

Explain or show how she could do this <u>and</u> give the answer that Marcy should get for the number of dots.

NAEP 6 point rubric for scoring:

0	No response
1	Student work is completely irrelevant or writes "I don't know"
2	Minimal – Student attempts to generalize or draws all 20 pictures in the pattern.
3	Partial – Student provides a partially correct generalization
4	Satisfactory – Student provides a correct generalization, but does not provide a correct 20th step solution.
5	Extended - Student provides a correct generalization, <u>and</u> the correct answer for the 20th step.