Mathematics and/or Science Education: Separate or Integrate?

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Abstract

The practice of integrating mathematics and science curricula at the secondary school level to improve student performance is a popular notion that intuitively seems appropriate and effective. A review of the literature, however, provides minimum support of this claim. Nevertheless, both mathematics and science standards recommend integration of mathematics and science curricula. The purpose of this paper is to discuss the issues surrounding integrating mathematics and science curricula by investigating current research. Obstacles and resolutions are included as well as a proposed model.

Background

Both mathematics and science education are highly influenced by standards developed by professional organizations. For math, the National Council of Teachers of Mathematics [NCTM] (2000) produced Principles and Standards for School Mathematics. This document purports six principles for school mathematics and five curriculum and five process standards. Similarly, the National Research Council [NRC] (1996) produced National Science Education Standards that provides standards for science teaching, learning, and professional development.

Included in both of these standards are recommendations to connect mathematics and science. For example, NCTM's Principles and Standards for School Mathematics (2000) contains a process standard, "Connections." The Connection standard states that students should be able to "recognize and apply mathematics in contexts outside of mathematics (NCTM, 2000, p. 66). The link between mathematics and science goes beyond process; NCTM recognizes that science content and process permeates the study of math. In a parallel fashion, The Science Education Program Standards (NRC, 1996, p. 214) include "C: The science program should be coordinated with the mathematics program to enhance student use and understanding of mathematics in the study of science and to improve student understanding of mathematics." (See Table 7.1 of NRC, 1996, which provides examples of mathematics that students should use and understand for grades K-4, 5-8 and 9-12.)

Many state standards recommend or require the use of mathematics in science. For example, the Science Texas Essential Knowledge and Skills [TEKS] (Texas Education Agency [TEA], 1997a) require students to use mathematics in the process of learning science. The TEKS either specifically require it as in high school Chemistry which states "The student is expected to: express and manipulate chemical quantities using scientific conventions and mathematical procedures such as dimensional analysis, scientific notation, and significant figures" (TEA, 1997a, Section 112.45). Or mathematics is required in general terms as in other high school or K-8 courses such as Grade 8 Science whose requirement for scientific inquiry includes "The student is expected to: collect data by observing and measuring; organize, analyze, evaluate, make inferences and predict trends from direct and indirect evidence; communicate valid conclusions; construct graphs, tables, maps and charts using tools including computers to organize, examine and evaluate data" (TEA, 1997a, Section 112.24). Likewise, the middle school mathematics TEKS convey the same message. For example, "The student applies grade 6 mathematics to solve problems connected to everyday experiences, investigations in other disciplines, and activities in and outside of school" (TEA, 1997b, Section 111.22).

Review of Literature

Integration of Mathematics and Science Content

A review of the literature resulted in only one study that focused on mathematics and science integration with respect to content. Judson and Sawada (2000) conducted a study that used science inquiry-oriented activities with data generating technologies to integrate math, specifically statistical concepts and techniques, into one eighth-grade science class. The science teacher attended an Arizona Collaborative for Excellence in the Preparation of Teachers [ACEPT] physics and mathematics summer seminar where he learned to use Calculator Based Laboratories [CBLs]. CBLs are data collection devices that provide a way for students to collect and analyze data with a variety of probes that can be used with or without calculators or computers. The experimental group of students was in the integrated science class while the control group was not. However, both groups received regular mathematics instruction. With the experimental group the science teacher used the CBLs, graphing calculators, and probeware as a way to integrate mathematics learning into the science class. Based on the results from the mathematics statistics unit test given to both groups, integration positively affected students' performance in their mathematics class. Only 35% of the students in the control group had grades of an A or B on the mathematics statistics unit test, whereas 75% of the students had grades of an A or B in the experimental group. There was no difference in science performance between the students in the integrated science class and the students in the nonintegrated science classes.

Note that the Judson and Sawada (2000) study incorporated mathematics into a science class. There are no studies targeting the inclusion of science content into a mathematics class. Moreover, research regarding a true hybrid course, one in which neither mathematics nor science dominate, is also not available.

Integration of Mathematics and Science Processes

Although it may be difficult to divorce process from content and studies that target process are only now surfacing, the review of the literature resulted in three studies that measured the impact of integrating mathematics and science on student performance in terms of process in either of the two disciplines. Westbrook (1998) studied how students' conceptual organization of concepts is affected by participation in a ninth-grade integrated algebra and physical science class. The experimental class was team taught by a mathematics and science teacher. The control physical science class was taught by a science teacher. Concept maps were completed by the students in order to assess their conceptual organization in science. According to these maps, the experimental group of students seemed more aware of procedural, as compared to relational, linkages between terms that connected mathematics and science. Westbrook defines procedural linkages as "valid connections among terms that indicated some action" (p. 89). Also, the experimental group tended to delineate more linkages among the terms than the control group. However, terms related to mathematics and science were sorted and placed in different locations on many of the experimental group's maps. This exhibited a "more compartmentalized approach to thinking about the content of the two disciplines" (p. 84). The students in the control physical science class seemed to "blend" the content of the two disciplines on their maps. Westbrook concludes that the conceptual complexity may have led to the experimental group's need to sort concepts before they develop a more integrated framework. If this is so, the observed compartmentalized thinking would be an expected outcome of learning in a cross-disciplinary context. Further research would be needed to examine this implication.

Merrill (2001) used a quasi-experimental nonequivalent control group design to investigate the impact of a researcher-developed integrated technology, mathematics, and science [TMaSe] curriculum at the high school level. The TMaSe used a Pedal-4-Power Energy Education Bicycle as a hands-on way to integrate the disciplines. The study was designed to address the following questions: 1) does the TMaSe curriculum affect immediate cognitive learning, 2) does the students' ability to distinguish connections between the three disciplines' concepts improve due to the integrated TMaSe curricula, and 3) is retention of TMaSe content improved over a long-term period of time. The experimental groups received the integrated, hands-on experience while the comparison groups received the identical content lessons, but without the integrated, hands-on component. The same technology teacher taught both groups. Three posttests were administered: one immediately after the treatment, one two weeks after treatment, and one four weeks after treatment. The results indicated that the experimental group (1) did not have significantly higher cognitive learning or (2) did not identify key terms or phrases that connect technology, math, and science in real-world situations as completely integrated compared to the comparison group. Additionally, the results did not show statistically significant gains in retention two and four weeks later. Merrill notes that the use of three teachers, one per discipline, might enhance the integrated teaching and learning due to greater content expertise. This is consistent with research that students with teachers with more content expertise have higher cognitive gains (Goldhaber & Brewer, 1998; Hawk, Coble, & Swanson, 1985).

In another study, Childress (1996) used a quasi-experimental nonequivalent control group design to investigate the impacts of integrating technology, science and mathematics [TSM] on process. The purpose of this study was to see if the National Science Foundation supported TSM curricula improved the ability of eighth-grade technology education students to solve the technological problem of designing an efficient wind collector. The experimental group received instruction from a mathematics and a science teacher who came into the technology class and taught concepts that were directly related to the technological problem that the students were trying to solve. The control group received instruction from a technology teacher, and the material was identical to the experimental group except without the specific mathematics and science instruction. Although both groups improved from the pretest to posttest, there was no significant difference between the groups on the posttest, which was based on the success of the device as measured by the wind collectors' mean electrical power output. Based on interviews with the students, the experimental group tended to consciously use science principles to solve problems during the investigation while the control group tended to rely on what the technology teacher taught and what other students did. The students were not assessed on their understanding of the individual mathematics and science concepts.

As with the content-based studies, the literature is void of investigations that utilize solely mathematics as a control group. Furthermore, process studies focusing on "seamless" integration, a blended, rather than an interdisciplinary course where discipline boundaries remain, are also missing from the literature review.

Overall, it appears that existing research in this area leaves room for additional studies. For instance, there is no research that focuses on middle school students. The aforementioned studies include two 8th grade, one 9th grade, and one high school level in general. Single-field disciplines are also not targeted. For example, either grade-level math, Algebra, or activity-specific mathematics is used. Geometry, a fundamental mathematics course, is not referenced, as is the case with Biology. Research methodology may also be improved upon. Sample sizes tend to be small and truly experimental studies have yet to occur. Currently, no replication studies exist and a trend of statistically significant results has yet to be achieved.

Barriers

As indicated by the scarcity of research and mixed results, there are obstacles that teachers must overcome in order to successfully integrate mathematics and science. Researchers cite many barriers to integration. Huntley (1998) lists several impediments based on teachers' perceptions of curricular integration, such as increased time, coordination of students, planning for instruction as a team, coordination of student assessments, availability of instructional models, and availability of appropriate curricular materials. The lack of communication due to many of these barriers may lead to fragmentation of concepts (Judson & Sawada, 2000). Frykholm and Glasson (2005) found that regardless of the natural overlaps in mathematics and science, teachers had little or no exposure to settings in which mathematics and science were connected. The teachers seemed affected by their lack of content knowledge in one or both of the areas which may be due to lack of training. In the mid 1900's, the National Center for Education Statistics recorded nationally representative data from the Schools and Staffing Survey (Ingersoll, 1999). The survey included several results. About one fifth of all secondary science teachers, grades 7-12, did not have at least a minor in one of the sciences or in science education. One third of all secondary mathematics teachers did not have either a major or minor in math, mathematics education, or other related subjects. The highest percentage of teachers in mathematics and science without a major or minor in that field occurred in seventh and eighth grade. In seventh grade general science classes, 31.8% of all teachers did not have a major or minor in that subject. In seventh grade life science classes, 60.4% of all teachers did not have a major or minor in that subject, which was low in comparison to the 75.7% of all eighth grade physical science teachers who did not have even a minor in that subject. If teachers do not have an adequate background in even one discipline, they are less likely to have preparation in another content area. Additionally, the strict scope and sequence of mathematics serves as a restriction when integrating mathematics and science (Judson & Sawada, 2000). The conceptual and structural development of mathematics may be reduced or eliminated due to the breakdown of mathematics instruction into a set of disconnected topics and skills

(West & Tooke, 2001). Conversely, since science uses mathematics as a tool during inquiry to describe phenomena and patterns and make predictions based on the patterns, the conceptual development of science may be enhanced by integrating math.

Possible Solutions

Factors have been identified that may aid in overcoming some of the barriers to integrating mathematics and science. One possible solution is identifying correlations between mathematics and science concepts in a teacher-friendly format (West & Tooke, 2001; West & Vásquez-Mireles, 2006). For example, Table I for Grade 7 Science identifies the required science concepts (TEKS) and the correlated Mathematics TEKS that when used by the science teacher during science instruction can enrich the students' understanding of mathematics concepts. Moreover, the tabular information format allows ease in lesson planning in regards to documentation and coordination. Correspondingly, Table II, indicates the correlation between the skills in mathematics and concepts in science for 7th grade students in TEKS

If each state would provide similar charts that correlate the state mathematics and science standards, teachers may find integrating mathematics and science more doable. Since both the mathematics and science TEKS are based on national standards, states may find the task of developing their own state mathematics and science correlation charts an easy one by using the existing Texas ones as a beginning.

Other factors may facilitate mathematics and science integration such as professional development, scheduling of classes, and acquisition of materials. A joint planning period for the mathematics and science teachers will provide teacher of both disciplines the opportunities to develop common explanations and examples to use in their respective classes so that concepts do not get fragmented (Huntley, 1998).

Frykholm and Glasson (2005) noted the importance of content knowledge needed in both mathematics and science and the need to develop appropriate pedagogical strategies to handle the overlaps in content. They recommend that prospective mathematics and science teachers be required to take additional coursework to enhance their knowledge of both disciplines. Also, they suggest that beginning teachers engage in "active learning opportunities in which authentic contexts provide fertile ground for understanding mathematics and science connections" (Frykholm & Glasson, 2005, p 138). Creating a methods course that integrates mathematics and science will allow preservice teachers to explore and observe connections between the two disciplines (Roebuck & Warden, 1998).

Miller and Davison (1999) propose a possible solution implied by the National Science Education Standards and the Benchmarks for Science Literacy in both mathematics and science, which suggests a change in the role of teaching and learning in the classroom. A paradigm shift from a teacher-directed instructional emphasis to one where students are more actively involved in the learning process could lead to better integration of the two disciplines.

Recommendations

Based on the review of literature and national and state standards there is a need for effective methods of integrating mathematics and science. A project titled "Mix It

Up" funded by the Texas Teacher Quality Program aims to address this need. The development of mathematics and science content knowledge and appropriate pedagogy whose importance is noted by Frykholm and Glasson (2005) will be addressed by this project whose goal is to improve both mathematics and science content and pedagogy as well as model integration of mathematics and science. Using a Middle School Science Module developed by West (www.bio.txstate.edu/57Escied/MS_Science), a sequence of TEKS-based science topics will be taught along with the correlated mathematics concepts. For example, during the inquiry lesson on the physics concept of position, the mathematics concept of planar coordinates is included. This integration of mathematics can enrich the understanding of the concept of position. Conversely, when the concept of position is taught, it can enrich the understanding of the mathematics concept of planar coordinates. Additionally, the instruction will include a reflection time after each lesson by the mathematics and science instructors on the problems, possible solutions, and rationale for the chosen solution of how to best integrate the concepts. Lastly, the project teacher teams will be required to design and teach an integrated lesson to a group of middle school students after the teachers have been taught the mathematics and science concepts separately to ensure their understanding of the concepts. This practice teaching will provide an immediate opportunity to field test their integrated lesson. The lessons will be video taped for later reflection and class discussion.

As part of the program evaluation, pre/posttests will be used to measure teacher cognitive gains. During the school year state student mathematics and science test scores from the pre-treatment year 2005 and post-treatment years 2006 and 2007 will be used to measure student cognitive gains. In this way we hope to measure the ultimate goal for any teacher professional development – classroom impact.

Table I
The Correlation between the Concepts in Science and the Skills in Mathematics for 7th Grade Students in TEKS

Science Concepts (TEKS)	Mathematics Skills (TEKS)
1	9,13
2	1,4,7,8,9,10,11,12,13,14,15
3	4,10,11,13,14,15
4	3,4,5,9,13,14
5	10,12,13,14
6	2,3,4,5,9,13,14
7	1,2,3,13,14,15
8	3,5,13,14
9	9,13
10	3,13
11	9,13
12	9,12
13	1,6,9,11,13,14
14	9,13,14

Table II
The Correlation between the Skills in Mathematics and the Concepts in Science for 7th Grade Students in TEKS

Mathematics Skills (TEKS)	Science Concepts (TEKS)
1	27,13
2	6,7
3	4,6,7,8,10
4	2,3,4,6
5	4,6,8
6	13
7	2
8	2
8	2
9	1,2,4,6,9,11,12,13,14
10	2,3,5
11	2,3,13
12	2,5
13	1,2,3,4,5,6,7,8,9,10,11,13,14
14	2,3,4,5,6,7,8,13,14
15	2,3,7

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