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ABSTRACT

Integrated mathematics and science teaching and learning is a widely advocated yet largely unexplored phenomenon. This study involves an examination of middle school integrated mathematics and science education from two perspectives: in theory and in practice. The theoretical component of this research addresses the ill-defined nature of the phrase "integrated mathematics and science education", and presents a conceptual framework in the form of a Math/Science Continuum to lend clarity and precision to this phrase. The theoretical framework was used to guide the design and implementation of the second component of this research, a qualitative investigation of two case studies of middle school integrated mathematics and science education. Following an outline of the design of this study, results from the two case studies are presented. This paper concludes with a discussion of three implications of this study for teaching and teacher education. Contains 18 references. (Author)

Theoretical and Empirical Investigations of Integrated Mathematics and Science Education in the Middle Grades

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Integrated mathematics and science teaching and learning is a widely advocated yet largely unexplored phenomenon. This study involves an examination of middle school integrated mathematics and science education from two perspectives—in theory and in practice. The theoretical component of this research addresses the ill-defined nature of the phrase *integrated mathematics and science education*, and a conceptual framework in the form of a *Math/Science Continuum* is presented to lend clarity and precision to this phrase. The theoretical framework was used to guide the design and implementation of the second component of this research, a qualitative investigation of two case studies of middle school integrated mathematics and science education. Following an outline of the design of this study, results from the two case studies are presented. This paper concludes with a discussion of three implications of this study for teaching and teacher education.

Theoretical and Empirical Investigations of Integrated Mathematics and Science Education in the Middle Grades

Introduction

Goals and objectives of school curricula are generally defined in strands paralleling traditional academic disciplines. That organization becomes particularly prominent in the experiences of students as they move into the middle grades where instruction is often given by content specialists in separate courses. Separation of the content strands has become characteristic of the school curriculum, with separation deepening as one progresses up the grades to high school and beyond (House, 1990). Mathematics and science are no exception to this general trend. Two hundred years ago scientists were likely to be conversant with all the fields of mathematics and science; scientists worked in only one or two fields, but managed to keep abreast of important developments in all areas. At that time school work covered the gamut of mathematics and science under the title *natural philosophy*. With the exponential growth of knowledge over these last two centuries, only a very few people can keep up with more than a small subarea within a field as broad as natural philosophy. This has caused fragmentation of the field into different disciplines—mathematics, physics, chemistry, biology, and the like (Education Development Center, 1969).

Even though the mathematics and science curricula have become separate, there has always been an undercurrent of support for their integration, with support waxing and waning over time (Berlin, 1991; House, 1990). At present, there is extensive support for integrating the teaching and learning of mathematics and science (e.g., National Council of Teachers of Mathematics, 1989; American Association for the Advancement of Science, 1990; National Research Council, 1996). The current widespread support for teaching mathematics and science in an integrated fashion in the school curriculum is advocated as a means by which students can develop deeply organized knowledge structures that are richly interconnected. In other words, integrated mathematics and science is encouraged as a way for students to acquire conceptual, as opposed to procedural knowledge of mathematics and science. Despite these expectations, there has only been scant research and experimentation investigating that hypothesis (Berlin, 1991). Not only is there an absence of research related to integrated mathematics and science education, it is difficult to reliably and validly compare the few existing studies due to the inconsistency with which the term *integration* is used; in fact, many research documents are only tangentially related to integrated mathematics and science education (Berlin, 1991).

Unlike the study of natural philosophy 200 years ago, where all the fields of mathematics and science were taught together, the meaning of the present-day term *integrated mathematics and science education* is not clear. What is integrated mathematics and science education? Does teaching mathematics through problem solving, where science is used solely for problem context, constitute integration? What about science instruction that focuses on problems and laboratory experiments with mathematics used merely as an analytical tool? Or do only teaching and learning situations in which the connections between mathematics and science are fully exploited, with mathematics and science playing synergistic roles in explaining the world in which we live, exemplify integrated mathematics and science education? One working group at the 1991 national conference on integrated mathematics and science suggested a Turing-type test for determining whether instruction is integrated. This test involves sending a visitor to the class in question, and if that visitor has difficulty distinguishing whether the class is a mathematics class or a science class, then one could say that mathematics and science are integrated (Berlin & White, 1994). To complicate this definitional problem, there is a plethora of terms commonly used to refer to *integration*. These terms reflect various conceptions and degrees of integration and are often used in nonuniform ways by teachers, educational researchers, teacher educators, curriculum developers, and policy makers (Berlin, 1991).

There may never be consensus as to how to define *integrated mathematics and science education*. But, this problem aside, research on integrated mathematics and science education has typically attempted to determine the effect of integration on students' mathematics achievement and/or mathematics attitude, or science achievement and/or science attitude, but not the effect on the achievement and attitude related to both disciplines (Berlin, 1991). What is lacking is research that documents the larger picture of teaching and learning in classrooms in which mathematics and science are taught in an integrated fashion.

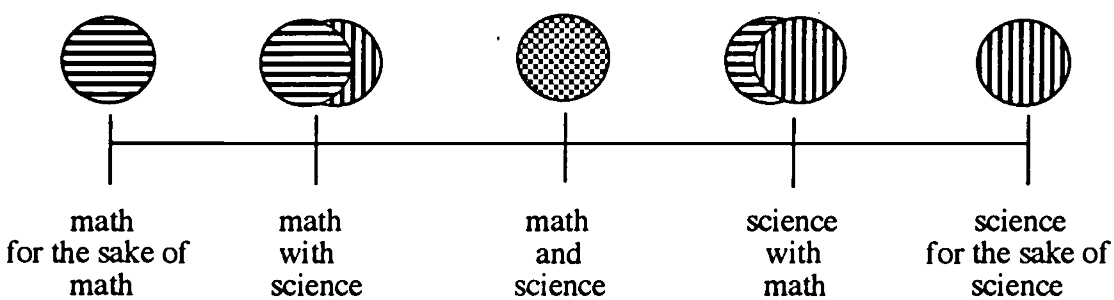
To address these gaps in the knowledge base, a research study was conducted to examine middle school integrated mathematics and science education from two perspectives—in theory and in practice. The theoretical component of this research addressed the ill-defined nature of the phrase *integrated mathematics and science education*, and a conceptual framework in the form of a *Math/Science Continuum* was developed to lend clarity and precision to this phrase. The theoretical framework was used to guide the design and implementation of the second component of the research, a qualitative investigation of two case studies of middle school integrated mathematics and science education. Two of the goals of this empirical investigation were: (1) to investigate teaching and learning in classrooms where mathematics and science are taught in an integrated fashion; and (2) to examine the beliefs of teachers of integrated mathematics and science.

The purposes of this paper are twofold. First, the theoretical framework for defining *integrated mathematics and science* is presented as a means of facilitating communication between groups of people who have a strong interest in integrated mathematics and science education. Second, results from an empirical investigation of middle school integrated mathematics and science will be outlined, including a discussion of the implications for teacher education.

Defining "Integrated Mathematics and Science Education"

A careful examination of the ill-defined phrase *integrated mathematics and science education* led to the recognition that while there may never be consensus as to its meaning, teachers, administrators, teacher educators, educational researchers, curriculum developers, and policy makers are strongly urged to define what they mean when using this phrase so as to facilitate communication and avoid unnecessary confusion. Before turning attention to the specifics regarding the particular combination of disciplines mathematics and science, note that adoption of a common language in the educational community regarding the general terms *intradisciplinary*, *interdisciplinary*, and *integrated* education would be a first step toward recognizing this goal. These three terms represent variations of curricular organization that increase in complexity and extent of integration. Based on a review of the literature, it is concluded that an *intradisciplinary curriculum* is typified by instruction that focuses on one discipline. An *integrated curriculum* is one in which there is an explicit assimilation of concepts from more than one discipline by the teacher(s) during instruction, and is typified by approximately equal attention to two (or more) disciplines. This differs from an *interdisciplinary curriculum*, in which the focus of instruction is on one discipline, and other discipline(s) are used to support or facilitate content in the first domain. In this case, connections between the disciplines are made only implicitly by the teacher(s).

Now consider curricular integration in the context of the particular disciplines mathematics and science. As articulated by Steen (1994), most educators recognize the value in students understanding and recognizing the connections between these disciplines in addition to fundamental differences between them. Course structure traditionally has been regarded as an either-or polarity: either courses are integrated across subject areas, or they are discipline-specific, but not both. This has resulted in a range of conflicts, from a lack of clarity in curriculum design to real tension that emerges among teachers (Jacobs, 1989). Thus, recognizing the value in teaching mathematics and science with varying degrees of overlap between the disciplines, as appropriate, consider the five categories for describing various interactions between mathematics and science that participants at the 1967 Cambridge Conference defined: *mathematics for the sake of mathematics*, *mathematics for the sake of science*, *mathematics and science*, *science for the sake of mathematics*, and *science for the sake of science* (Education Development Center, 1969). Transforming these discrete categories into continuous categories, the different possibilities regarding the extent of interaction between mathematics and science during instruction can be represented in a *Math/Science Continuum*, as shown in Figure 1. The *Math/Science Continuum* is offered as a means to clarify the overlap or coordination between the disciplines during instructional practice. The ends of this continuum represent the separate approach to mathematics and science instruction. Moving towards the middle of the continuum represents an increased infusion of one discipline (mathematics or science) into the teaching and learning of the other discipline (science or mathematics). The middle of the continuum represents full integration of mathematics and science. Note also that a foreground/background metaphor is used to convey which discipline is the focus of instruction—the circle with horizontal stripes represents mathematics, and the circle with vertical stripes represents science.



math for the sake of math
a math course that presents math as a formal system

math with science
a math course in which science (content and/or methods) is used to establish problem context and relevance

math and science
math (content and methods) and science (content and methods) course in which these two disciplines play synergistic roles in explaining the world

science with math
a science course which emphasizes math (content and/or methods) as a tool for solving scientific problems

science for the sake of science
a science course in which the habits and instincts of working scientists (science content and/or methods) dominate

Figure 1. Math/Science Continuum

An Empirical Study of Middle School Integrated Mathematics and Science

The framework presented in Figure 1 was used to guide the selection of participants for an empirical investigation of middle school integrated mathematics and science, and was then used to guide the analysis of data collected in this study. Details of this investigation are discussed in this section, including the design of the study, results, and implications for teaching and teacher education.

Overview of the Empirical Investigation

The goal of this study was to provide descriptive and analytical accounts of teaching and learning in middle school classrooms where mathematics and science are taught in an integrated fashion. *Integration* in this context means that mathematics and science are taught together irrespective of traditional disciplinary boundaries. With respect to the math/science continuum in Figure 1, this situation is represented at the middle of the continuum—*math and science*. To capture the complexities and idiosyncrasies of integrated mathematics and science teaching and learning, observational case studies were conducted in two specific settings where full integration of the disciplines was attempted. This was an exploratory study—designed to provide insight into teaching and learning mathematics and science in an integrated fashion, and to suggest aspects of this phenomenon that warrant future investigation. This investigation utilized a qualitative mode of inquiry emphasizing description, induction, grounded theory, and the study of people's understandings.

The selection of participants for the study was based on two criteria: (1) that they teach at the middle school level; and (2) that their goal of instruction is to dissolve the disciplinary boundaries between mathematics and science. Based on these criteria, two sets of middle school teachers in the mid-Atlantic region of the United States were invited and agreed to participate in this research. Two factors motivated the choice to examine integrated mathematics and science at the middle school level. First, fragmentation of the curriculum generally begins during the middle school years and deepens as students progress through the grades (House, 1990). For that reason, consideration was made to document and analyze the phenomenon of integrated teaching and learning at the root—the stage where fragmentation typically becomes the norm. Second, according to the Carnegie Council on Adolescent Development (1996), education at the middle school level was largely ignored by the educational reforms of the 1980s, and in the present decade there is increased attention to make up for this deficit. In particular, it is recognized that the curriculum in middle schools is so fragmented with respect to subject matter that students have few opportunities to make connections among ideas in the different academic disciplines (Carnegie Council on Adolescent Development, 1996). Thus, research on teaching and learning in the middle-grade levels, particularly as it concerns integration of the content strands, is relevant to current educational reform.

To study the intricacies of integrated mathematics and science teaching and learning, classroom observations were the major source of data collection. During these observations classroom instruction was videotaped and extensive field notes were taken. In an effort to avoid sporadic visits, each classroom was visited for two nonconsecutive weeks. This provided the opportunity to see how lessons, and the mathematical and scientific content contained therein, fit into larger instructional units. For the purpose of triangulation, data was collected from several additional sources: self-reported data from teachers, semi-structured interviews with teachers, and artifacts.

While substantial reflection occurred while in the field, the majority of data analysis took place after the completion of data collection. After data collection, data analysis consisted of two major components. One component concerned analysis of the beliefs of teachers of middle school integrated mathematics and science. For this analysis a variant of the method of analytic induction was used by employing strategies described by Bogdan and Biklen (1992), LeCompte and Preissle (1993), and Miles and Huberman (1994). The second component concerned analysis of the mathematical and scientific tasks in which students were engaged during classroom instruction. For this analysis the *Integrated Mathematics/Science Analytical Scheme* was developed, based on the *QUASAR Classroom Observation Instrument* (Stein, Grover, & Silver, 1991).

In the two cases of middle school integrated mathematics and science that were examined, the pairs of teachers had the same instructional goal: to integrate the teaching and learning of these disciplines to the extent that a visitor observing the class would be unable to distinguish whether the class was a mathematics class or a science class. All four teachers have extensive experience teaching at the middle school level; in fact, each has between 15 and 25 years of teaching experience. However, one set of teachers (Ms. Clark and Mr. Lewis) has been teaching mathematics and science in an integrated fashion for 5 years, while the other set (Mr. Armstrong and Mr. Aldrin) was just beginning to integrate their teaching when this investigation took place.

Case 1: Ms. Clark and Ms. Lewis

Ms. Clark holds a bachelor's degree in special and elementary education and a master's degree in English literature. She has 15 years experience teaching middle school students and has taught a wide range of subjects—from math and science to art, reading, and social studies. Ms. Clark actively participates in her professional community—giving talks, assuming leadership roles in her school, providing consultant services, and applying for and receiving numerous grants. Ms. Clark has a strong interest in, yet has had limited formal coursework in mathematics. She was in the accelerated mathematics program during high school and earned college credit for successfully completing advanced placement calculus in twelfth grade. Ms. Clark reports that she took an early interest in science, and was fascinated by the processes of science, namely, conducting experiments involving controlled and manipulated variables. An important component of Ms. Clark's belief system is the value she places on the ability to think critically—the ability to explain ideas clearly, accurately, and precisely—irrespective of discipline. When asked to describe the relationship between mathematics and science during her interview, she stated that "it all has to do with thinking." Ms. Clark reports that she does not "distinguish by discipline well at all . . . . I distinguish by level of precision of thinking more than anything else, and willingness to think precisely . . . and . . . to manipulate abstractions."

Mr. Lewis holds a bachelor's degree in sociology/anthropology and has completed graduate coursework in education. Except for two years that he spent as a master teacher at the elementary school level, Mr. Lewis has spent the remainder of his 15-year career teaching at the middle school level. Like Ms. Clark, he has taught a variety of subjects, and actively seeks out opportunities to give presentations at professional meetings, apply for grants, and provide consultant services. Mr. Lewis has had limited mathematics coursework and experiences. He took algebra, geometry, and trigonometry in high school, but did not take any mathematics courses in college. Mr. Lewis attended a parochial school up until the ninth grade, at which time his formal science education began. In high school he took courses in biology, earth science, and chemistry, and he recalls especially liking the laboratory work as opposed to the lectures given during class time. Having been an anthropology major in college, Mr. Lewis said he frequently encountered the processes of science, such as making observations and collecting data.

Ms. Clark and Mr. Lewis hold similar views concerning teaching and learning. Both appreciate differences in learning styles that students bring to their classrooms. While they believe that students learn best when they construct their own knowledge of concepts, they also sees value in students practicing problem solving through drill and repetition. In addition, Ms. Clark and Mr. Lewis believe that students benefit tremendously when given opportunities to work in heterogeneous cooperative learning groups because they are exposed to other students' ways of learning. Ms. Clark and Mr. Lewis do not endorse any one specific teaching approach. As conveyed in her interview, Ms. Clark feels strongly that various approaches to teaching "are necessary to meet students' needs and really teach." Similarly, during his interview, Mr. Lewis emphasized the importance of recognizing differences in students' learning styles as follows: ". . . there are all those different ways that they need to see it, hear it, and try it."

Ms. Clark and Mr. Lewis structure their teaching around three components, or strands, of instruction—*Fundamentals*, *Integrated Station Performance Units*, and *Research Course*. In this way, students are provided with a wide range of learning experiences in a variety of settings in an effort to accommodate differences in students' learning styles and to provide many opportunities for students to be successful in mathematics and science.

According to Ms. Clark and Mr. Lewis' instructional plan, each day begins with a 30–40 minute session of *Fundamentals*. During this time students are homogeneously grouped according to mathematical ability, and engage in remedial, developmental, or enriched mathematics lessons. It was observed that both Ms. Clark and Mr. Lewis maintain intellectual authority throughout *Fundamentals*. In particular, both teachers valued speed and accuracy as criteria of success, and funnelled classroom discourse toward getting the correct answer as opposed to eliciting students' solution strategies and reasoning. Students were only rarely asked to justify their answers or explain their reasoning; when they were, it seemed to be for reporting purposes as opposed to eliciting alternative responses from other students. When students gave incorrect answers, their responses were usually dismissed without further discussion. For example, the following dialogue, which is typical of teacher-student discourse in Mr. Lewis' classroom, took place during a whole-class discussion:

Mr. Lewis:	What do you call the sides of a rectangle?
Student 1:	Perimeter.
Mr. Lewis:	No.
Student 2:	Area.
Mr. Lewis:	No.
Student 3:	Width and length.
Mr. Lewis:	Yes, the width and the length.

Students were rarely offered the opportunity to engage in student-to-student discourse during *Fundamentals*. Although Ms. Clark and Mr. Lewis stated (in a note they sent to parents) that the goal during the *Fundamentals* strand is to teach mathematical concepts and promote mathematical reasoning, their choice of textbook (non-reform-inspired), mode of teaching, and expectations for student performance indicated that they valued drill and practice, repetition, and rote memorization for learning basic mathematical skills. Students were also expected to practice basic mathematical skills every night by working through assigned homework. Since mathematics was not presented in any context during *Fundamentals*, the disciplinary focus was *mathematics for the sake of mathematics.*

Three days per week the *Fundamentals* period is followed by what Ms. Clark and Mr. Lewis call *Performance Unit Station Rotations* (*Stations*). Students are divided into three approximately equal-sized heterogeneous groups for *Stations*, with one third of the students working with Ms. Clark in her classroom at *Knowledge Stop*, one third working with Mr. Lewis in his classroom at *Integrated Laboratory*, and one third working, with minimal teacher guidance, at one of two *Cooperative Learning Stations*, one of which is located in Ms. Clark's classroom, and the other is located in Mr. Lewis' classroom. Throughout the course of a week all students participate in all three of these components. Within each component students are encouraged to work cooperatively in groups of size 3–4, and are frequently reminded by Ms. Clark and Mr. Lewis of strategies for how to work productively in cooperative group learning situations. Students are encouraged to use calculators and computers during *Stations*, as appropriate.

Ms. Clark's *Knowledge Stop* lessons were observed for a total of five days. A typical instructional pattern began with Ms. Clark setting up some activity for students either by giving directions orally or by modelling the solution process for a typical problem. Students were then given some time to work on the activity with their groupmates, which was followed by a whole-class discussion. During *Knowledge Stop* lessons students were asked to apply mathematics to some problem situation set in a scientific or everyday context. While students sometimes learned a bit about the problem context, in general the focus was on extending students' mathematical skills, such as number conversion and plotting points on an (x,y) axis, to applied problems. Hence, the relationship between the disciplines is best characterized as *mathematics with science.*

Mr. Lewis' *Integrated Laboratories* were observed for seven days altogether. A typical instructional pattern began with Mr. Lewis asking students to copy some information into their notebooks from the overhead projector, either in the form of text or a diagram. Several minutes later he would return and intersperse whole-class discussions and demonstrations with cooperative group activities. The tasks in which students were engaged during *Integrated Laboratory* were usually presented in prescriptive fashion, allowing them virtually no opportunities to make sense of mathematics and/or science. The activities during *Integrated Laboratory* consisted primarily of scientific investigations that utilized some mathematics, including counting, adding and multiplying fractions, and calculating such quantities as the diameter of a circle, the area of an irregularly-shaped object, and the density of an object given its mass and volume. In all cases students were expected to use mathematics to gain further insight into a scientific phenomenon. While students sometimes learned a bit about mathematics, this learning focused on the processes of mathematics more so than on mathematical topics. In general the focus was on extending students' science content knowledge. Hence, the relationship between the disciplines is best characterized as *science with mathematics.*

Ten observations were made during *Cooperative Learning Station* activities, which often involved the use of computer software in the form of games or tutorials. While these activities were to be done in cooperative groups with minimal teacher support, Ms. Clark and Mr. Lewis always gave students directions before they began their activity; these explanations often included their modelling how to solve a typical problem or demonstrating which keys to press on the keyboard to run the software. When students were engaged in *Cooperative Learning Station* activities, they were repeatedly reminded to follow the directions exactly as stated on their worksheets, and to answer all questions on their worksheets. Because these worksheets contained detailed directions for students, and the questions generally required short, fill-in-the-blank responses, students in *Cooperative Learning Station* activities had minimal opportunities to engage in mathematical and scientific reasoning or exploration of ideas. While some *Cooperative Learning Station* activities consisted of mathematical investigations with science used for problem context, other activities consisted of scientific investigations with mathematics used for counting and graphing purposes. Thus, these activities can be best characterized as involving *mathematics with science*, and *science with mathematics.*

In summary, during *Knowledge Stop*, *Integrated Laboratory*, and *Cooperative Learning Stations*, the tasks in which students were engaged were presented in prescriptive fashion, allowing them virtually no opportunities to make sense of mathematics and/or science. During the whole-class discussions in each of these segments, the teachers maintained intellectual authority and focused on how to get right answers, as opposed to discussing mathematical and scientific ideas, verifying conjectures, and reflecting on the thinking involved in solving problems. In these components of instruction, the disciplinary focus was either mathematics or science, but not both. Such instruction is better characterized as being *interdisciplinary*, as opposed to *integrated*.

Two days a week the math *Fundamentals* period is followed by the *Research* strand. Altogether six classroom observations were made on *Research* days—three times Ms. Clark was observed and three times Mr. Lewis was observed. During these observations a total of seven tasks were observed. Based on observations during the *Research* strand of instruction, it appeared that Ms. Clark's and Mr. Lewis' instructional goals included helping students develop the habits of working scientists. An important component of scientists' work is maintaining detailed notes concerning all aspects of their investigations of objects or phenomena. This skill—keeping an updated *Research Notebook*—was emphasized during all observations. The nature of students' questions during *Research* were procedural—they concerned procedures for entering information into their notebooks, and steps required to conduct science investigations. During classroom observations of *Research*, the primary disciplinary focus was science, specifically, environmental and earth sciences. In addition to learning background information, instruction focused on dependent and independent variables (the distinction between them, and the effect on dependent variables when independent variables are changed), and procedures for conducting scientific experiments and simulations (prediction, data collection, and data analysis). Mathematics entered into the investigations mainly in the form of arithmetic calculations, counting, and graphing. In one instance Ms. Clark represented data in tabular and graphical forms, and while she emphasized to students that they were looking for a specific pattern or shape to the graph, there was no attempt to mathematize this pattern. During one observation Mr. Lewis asked students to use mathematics to convert quantities represented as percentages into fractions. In another case Ms. Clark asked students to convert a quantity given in milliliters to liters; in going over the solution to this problem she emphasized that they should expect a much smaller quantity because 1000 milliliters is equivalent to one liter, which means they would be dividing by 1000 to find the answer. Although there were several instances that lent themselves to development of mathematical reasoning, such as exploring patterns in data tables and graphs, students were afforded limited opportunities to do so during *Research*. Hence, the disciplinary content during the *Research* portion of instruction is best characterized as *science with mathematics.*

This descriptive and analytical account of Ms. Clark and Mr. Lewis' beliefs and classroom practices is used to investigate the following three issues which guided this empirical study: (1) the extent to which the boundaries between the disciplines mathematics and science were dissolved during classroom practice; (2) the extent to which the classroom environment supported opportunities for students to reason about and explore mathematical and scientific ideas; and (3) the extent to which the teachers used a facilitative as opposed to a directive or modelling approach to instruction.

Ms. Clark and Mr. Lewis begin each day with a 45–60 minute period of mathematics taught in isolation (*Fundamentals*), followed by a 45–60 minute project-based activity that includes both mathematics and science (either *Stations* or *Research*). Content covered in one strand of the curriculum is reinforced in other strands; in other words, students see the same disciplinary content in a variety of contexts and through a variety of instructional strategies. However, during each strand it appeared that the focus was on student learning of content from one discipline—either mathematics <u>or</u> science—but not both. While some investigations focused on new mathematics material set in the context of science (*mathematics with science*), and some investigations focused on new science material that used mathematics as a tool (*science with mathematics*), there were no activities observed where the goal was learning of new material from both the mathematics domain <u>and</u> the science domain. While some activities had opportunities for development of both mathematical and scientific content, this potential was never realized. I hypothesize that a contributing factor to the absence of strong connections between the disciplines during these two activities may be the fact that both Ms. Clark and Mr. Lewis have had limited coursework, past the high school level, in the disciplines mathematics and science. It seems reasonable that a necessary prerequisite for teaching integrated mathematics and science is solid understanding of these disciplines. In other words, a teacher's capacity to capitalize on the many connections between mathematics and science—the ability to make integrated lessons more powerful than separate instruction in mathematics and science—is dependent upon the mathematics and science content knowledge of the teachers providing instruction. If teachers have limited understandings of the disciplines mathematics and science, then it seems reasonable that their capacity for making deep connections between the disciplines during classroom instruction is similarly quite limited.

Using the math/science continuum outlined in Figure 1, Figure 2 illustrates the ways in which the disciplinary focus of instruction shifted during the various curricular strands during classroom observations.

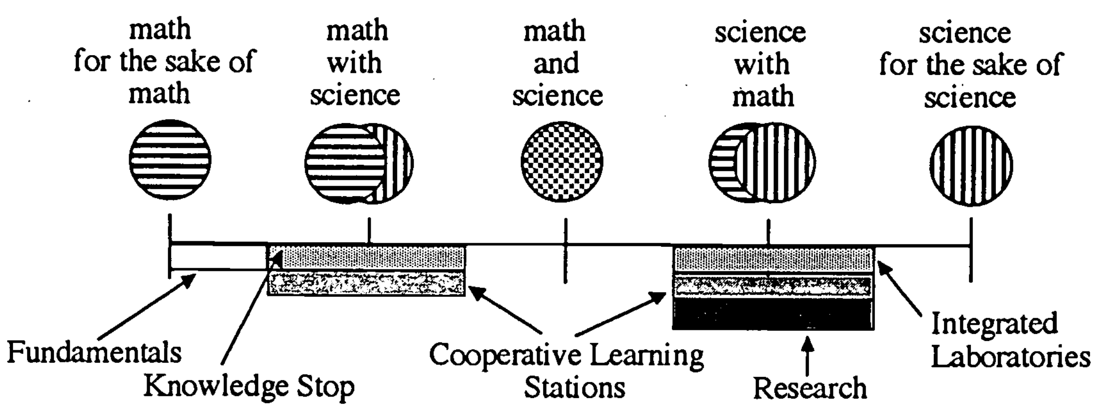


Figure 2. Shifts in the Disciplinary Focus of Instruction During Classroom Observations

While Ms. Clark and Mr. Lewis describe their mathematics and science program as *integrated*, according to the terminology established earlier, their program is actually *interdisciplinary* in nature. Perhaps this conflict is an issue of semantics, as opposed to a difference between their beliefs and instructional practices. This hypothesis is further substantiated by the following passage, which is taken from a handout Ms. Clark and Mr. Lewis distribute during presentations at professional meetings:

> Teachers [Ms. Clark and Mr. Lewis] plan integrated lessons where there is [sic] objectives from both the math and science curriculums included on student worksheets. The content of the lessons depend on each other so that mathematics and science become tools for problem solving. The planning puts the *problem* [italics added] squarely in the middle of the planning session and it is the responsibility of each discipline teacher to incorporate their objectives into the lesson plans. Please note that there is a difference between theme teaching interdisciplinary and integrated problem solving interdisciplinary. A *theme* [italics added] puts a noun in the middle and does not necessarily create a problem situation where planning has to be dependent on each other. Integrated teaching creates a math/science lessons [sic] that are dependent on skills from each discipline to be completed.

Thus, Ms. Clark and Mr. Lewis state that they distinguish between two types of interdisciplinary teaching: *theme teaching* and *integrated problem solving*. However, they do not address the definitional issues regarding *integrated* versus *interdisciplinary* education. Hence, it is inferred that they intend to teach in an *interdisciplinary* fashion, rather than in an *integrated* fashion.

With one exception, Ms. Clark and Mr. Lewis took a directive or modelling approach to instruction by providing students with explicit directions for tasks either in verbal or written form. There was very little opportunity for students to conjecture, hypothesize, or reason about mathematics or science. There was no discussion of incorrect answers that students gave in response to questions, and Ms. Clark and Mr. Lewis, as opposed to the students, maintained intellectual authority during all lessons that were observed. While Ms. Clark and Mr. Lewis stated on their questionnaires that they valued a variety of instructional approaches, only one mode was observed. As a result, the cognitive demands of tasks were low. Students were expected to use recall and follow procedures laid out for them by their teachers.

These findings can be summarized as follows. First, although there were opportunities to integrate mathematics and science during classroom instruction, classroom observations indicated that integration occurred only to a limited extent. Second, although the tasks in which students engaged had the potential for stimulating high cognitive demand, the tasks, as implemented, required low cognitive demand from students. Third, although both Ms. Clark and Mr. Lewis stated that they value many approaches to classroom instruction, their classroom practices indicate that they only used a directive or modelling mode of instruction. These findings suggest a gap between integrated instruction in theory and in practice. This gap may, in part, be a consequence of barriers that Ms. Clark and Mr. Lewis face in their effort to integrate mathematics and science.

The early partners in discovery, Meriwether Lewis and William Clark, were driven partly by their own quest of adventure, partly by President Jefferson's desire to locate a feasible trade link between the Eastern United States and the Pacific, and partly by President Jefferson's intrigue with the notion that prehistoric creatures might be roaming the vast lands beyond the Mississippi. The result was Lewis and Clark's journeying farther into the largely unknown West than had any other Americans by forging up the Missouri River, struggling over the Rocky Mountains, and pressing on to the Pacific Ocean. Similarly, Ms. Clark and Mr. Lewis, driven by the strength of their convictions, their determination to find a way to make mathematics and science more meaningful and exciting for students, their willingness and ability to take professional risks, and support from their school principal, have journeyed into the largely unexplored educational territory of integrated education, enduring a myriad of struggles along the way. A discussion of those factors Ms. Clark and Mr. Lewis perceived to facilitate as well as limit their ability to teach mathematics and science in an integrated fashion gives further insight into teaching mathematics and science in an integrated fashion.

As reported by Mr. Lewis, one barrier to integrating mathematics and science is the absence of curricular materials that reflect their notion of integration, specifically, "it's very difficult . . . to imagine what a lesson is, that's . . . beyond data, statistics, and graphing." Another barrier Mr. Lewis reported is the absence of instructional models for integrated education. Mr. Lewis reported that this has led them to develop a program that he considers to be slightly haphazard: "there's no rhyme or reason or methodology or order to this [program] because . . . you're operating from a void. I haven't seen . . . a truly integrated program." Another barrier to integration concerns money. While Ms. Clark and Mr. Lewis currently receive funding from a philanthropical organization to teach mathematics and science in an integrated fashion at Jefferson Middle School, they applied for and received funding several years ago from the GTE Foundation in the form of a *Growth Initiatives for Teachers* (GIFT) grant to implement their program at their prior school. A large portion of this money was used to purchase resources to develop their environmental science program, and some money was used to attend professional development meetings.

Ms. Clark and Mr. Lewis explained that a potential barrier to integrating the school curriculum is the school administration. Ms. Clark and Mr. Lewis needed a supportive and flexible principal who would allow them to adjust their schedules and the location of their rooms so they could engage in joint activities with a shared set of students. Moreover, they needed supportive county mathematics and science supervisors. It had been their experience that while these supervisors offered supportive comments regarding their attempt to integrate the curriculum, and the supervisors communicated their understanding of potential benefits to students when mathematics and science is taught in an integrated fashion, these supervisors nevertheless lent their support only to a limited extent because of the pressures they themselves faced from the state to account for students' learning basic mathematical skills and facts. Based on limited classroom observations, these supervisors expressed doubt about whether Ms. Clark and Mr. Lewis were fulfilling their obligation to teach basic mathematical skills and facts. As explained by Ms. Clark and Mr. Lewis, these two factors—the limited support they received from their supervisors, and the fact that mathematics has a more well-defined scope and sequence than science in the school curriculum—have led them to structure their curriculum so that nearly half their instructional time is spent on student acquisition of basic mathematical skills (*Fundamentals*).

Case 2: Mr. Armstrong and Mr. Aldrin

During the summer prior to this investigation, Mr. Armstrong and Mr. Aldrin, teachers at Kennedy Middle School, were planning for the next school year. Unlike past years, with Mr. Armstrong teaching mathematics and Mr. Aldrin teaching science, their intent was to implement a new plan to team teach these disciplines in an integrated fashion for one group of students—

approximately 30 seventh-grade students who are in the highest academic track. Their goal was to create a classroom environment in which students could not distinguish whether they were in a mathematics class or a science class. As the school year unfolded, Mr. Armstrong and Mr. Aldrin encountered a number of complications that limited their ability to realize their original goal. As a result, the reporting of this case study focuses on the limiting factors and barriers these teachers faced when moving from a separate to an integrated approach to instruction.

Mr. Armstrong and Mr. Aldrin began to move toward integrating their teaching of mathematics and science two years prior to this study in what has evolved into their annual *Space Shuttle Project.* This is an interdisciplinary unit that involves all seventh-grade students in constructing and flying a space shuttle. While a few students actually "fly" the shuttle, other students participate by using computers to run a real-time data center to track the mission by plotting orbits and monitoring supplies. The duration of the simulation is 30 hours; provisions are made so that students remain at school overnight. Students in other grades at the school are kept abreast of developments through periodic updates and announcements via the intercom system. According to Mr. Armstrong, past students have conveyed to their younger siblings and friends their enthusiasm for the project, thereby making the project tremendously popular with students.

During the first implementation of the *Space Shuttle Project* two years prior to this investigation, Mr. Armstrong and Mr. Aldrin applied for and were awarded a *GIFT* grant from the GTE Foundation. This provided monetary support in the form of supplies and professional development to assist their integrating mathematics and science. They used this money for a variety of purposes. Mr. Armstrong ordered a classroom set of graphing calculators from Texas Instruments, and received training regarding the incorporation of the calculators into his classroom instruction. Mr. Aldrin used a portion of the funding to attend three conferences, and purchased a professional library that is used by teachers throughout the school. In addition, Mr. Armstrong and Mr. Aldrin jointly attended a regional National Science Teachers Association meeting, where they gave two joint presentations concerning their experiences with the *Space Shuttle Project.*

Mr. Armstrong and Mr. Aldrin reported that they planned to integrate their teaching of mathematics and science using money provided by the GTE Foundation by jointly planning other units, like the *Space Shuttle Project*, each of which focuses on a specific theme. In their planning a unit, they anticipated relying on their own expertise—Mr. Armstrong in mathematics and Mr. Aldrin in science—to find overlapping concepts relevant to both disciplines. Their goal was to build units around themes that involved both significant mathematics and significant science. They anticipated implementing their plan according to the following scheme: (1) a set of students would learn mathematics that is relevant to the theme from Mr. Armstrong during first period; (2) these students would proceed to Mr. Aldrin's classroom for science during second period, where they would engage in scientific investigations that involved the mathematics they learned in Mr. Armstrong's mathematics class; (3) in conducting these scientific investigations, students would encounter mathematics that they had not yet learned, which would be studied the next day in Mr. Armstrong's mathematics class. This pattern would be repeated in a cyclical fashion for the duration of the unit.

Mr. Armstrong and Mr. Aldrin are like-minded in the sense that they both strongly support the notion of teaching mathematics and science in an integrated fashion to enhance students' learning. Also, they both have extensive experience teaching their respective disciplines, their teaching is respected by their peers and supervisors, and they are able to and willing to take professional risks. Mr. Armstrong and Mr. Aldrin rely on each other for collegial support; several times Mr. Armstrong was observed asking Mr. Aldrin science-related questions, and it was reported that Mr. Aldrin frequently relies on Mr. Armstrong's mathematical expertise. In addition, Mr. Armstrong and Mr. Aldrin's teaming up to teach mathematics and science in an integrated fashion is a function of their personalities. This was described by Mr. Aldrin as follows: "We both kind of get excited, and, enthused about things, so it was just a logical match . . . . it was finding somebody that was willing to do it, and he was more than willing to do it."

The final steps toward Mr. Armstrong and Mr. Aldrin implementing their plan to integrate their mathematics and science teaching required administrative support from the school principal.

A pivotal feature of their plan, as described above, was that they share the same students, with students receiving mathematics instruction first from Mr. Armstrong, and then receiving science instruction from Mr. Aldrin. Another pivotal feature of their plan involved the coordination of their instruction, which required joint planning time. They required support from the school principal to implement these ideas. The new school principal, Mr. Collins, who was the former county mathematics supervisor, has tremendous respect and admiration for Mr. Armstrong's and Mr. Aldrin's teaching, and provided them with flexibility in scheduling classes that they needed to integrate their teaching of mathematics and science during the 1995–96 school year. With this administrative support, the final components of Mr. Armstrong and Mr. Aldrin's plan fell into place. Like astronauts awaiting liftoff, they eagerly began the countdown to the beginning of their first school year teaching mathematics and science in an integrated fashion.

Despite their careful planning, Mr. Armstrong and Mr. Aldrin reported that they could only integrate their teaching of mathematics and science to a very limited extent during the 1995–96 school year. In fact, very early into the school year they had resigned themselves to coordinating their teaching during only one instructional unit—the *Space Shuttle Project*. Many barriers limited their ability to implement their full plan.

Mr. Armstrong and Mr. Aldrin had anticipated that the changes in school structure that academic year—to block scheduling and regrouping of teachers into math/science teams—would facilitate their integrating their respective disciplines because it would allow them the flexibility to coordinate their students' schedules, and would allow them common planning time to coordinate their instruction. However, these changes did not have the anticipated results. The change to block scheduling necessitated their using a portion of their planning time to adapt their lesson plans to accommodate the longer class periods. Also, due to the many changes in scheduling, Mr. Armstrong and Mr. Aldrin began teaching courses in the 1995–96 school year that they had never before taught. As a result, their planning periods were often consumed with discussing immediate concerns related to their new responsibilities, as opposed to discussing ways to coordinate their instruction. Thus, while Mr. Armstrong and Mr. Aldrin considered the change to block scheduling and the regrouping of teachers into math/science teams to facilitate integration, they were experiencing a period of adjustment, which in effect, made their goal of integrating their disciplines unattainable in the short-term. As reported by Mr. Aldrin, after this period of adjustment he felt they would make more progress toward integrating mathematics and science. Mr. Aldrin noted that he feels they would have been further along with integrating their disciplines if they had done more extensive planning the summer prior to the 1995–96 school year. He was not optimistic about being able to complete this planning during the current school year, and was investigating the possibility of using their leftover GTE grant money during the following summer to support their planning of integrated thematic units.

Mr. Armstrong was particularly affected by time constraints during the 1995–96 academic year. Due to financial constraints the school lacked one science teacher, and given his strong science background and interest in science, Mr. Armstrong accepted an invitation from Mr. Collins to teach a period of seventh-grade science and a period of eighth-grade science. While this left him teaching only two periods of mathematics—one period of seventh-grade mathematics and one period of eighth-grade mathematics—within these two periods he taught five different groups of students. During the period of seventh-grade mathematics he taught a group of students pre-algebra and another group of students algebra. During the period of eighth-grade mathematics he taught a group of students algebra, another group of students algebra 2, and one student geometry. In all, Mr. Armstrong had to juggle seven different instructional preparations each day, placing severe constraints on his time. Thus, time was the major limiting factor to Mr. Armstrong and Mr. Aldrin integrating mathematics and science as they had planned.

During his interview, Mr. Armstrong explained that although he and Mr. Aldrin had planned to integrate mathematics and science for the seventh-grade students in the highest academic track, he was having second thoughts about this plan. His reservations stem from concern over content coverage. In the case of the most advanced seventh-grade students, those taking algebra, he feared that infusing science into the curriculum would slow their pace, and even worse, might not adequately prepare students for the standardized tests they will eventually take in high school.

Upon retrospect, Mr. Armstrong thinks that integration of mathematics and science might be more appropriate with students taking general mathematics: ". . . with the general math, it doesn't have the . . . constraint . . . . It's not as accountable. And so since it's not accountable . . . this is where I think you could make your big push [toward integration]."

Mr. Armstrong perceived his students' science background to lag far behind their mathematical ability, which presented another barrier to his teaching mathematics and science in an integrated fashion. Mr. Aldrin perceives teaching mathematics and science in an integrated fashion to require teachers to move away from textbook-oriented instruction. In general, he considers this to be more difficult for mathematics teachers than for science teachers: "Math has probably been more based on a textbook . . . . Traditionally, that's what math is. So it was a greater risk for him [Mr. Armstrong] to pull away from the book, and start focusing the math . . . around sometimes science concepts." On the other hand, Mr. Aldrin anticipates science teachers having difficulty incorporating more mathematics in their teaching because science teachers are less likely to know what happens in mathematics classes, whereas mathematics teachers usually have some notion of what happens in science classes.

Despite the fact that Mr. Armstrong and Mr. Aldrin did not achieve their desired goal, both felt satisfied that they had learned a great deal from their experience. As explained by Mr. Armstrong, while their plan for the continuation of concepts from his mathematics class to Mr. Aldrin's science class, and vice-versa, for <u>one</u> group of students did not work out as anticipated, <u>overall</u> the seventh- and eighth-grade mathematics and science teachers were increasingly emphasizing the connections between these disciplines (personal communication, October 19, 1995). Mr. Armstrong based this claim on progress he and Mr. Aldrin had made toward infusing more mathematics into students' math/science fair projects. In particular, they established the requirement that students collect measurable data which was to be represented and analyzed in some mathematical fashion. In addition, on the last day of the second week of observations, Mr. Aldrin reported that he had received a two-page summary from the mathematics teachers concerning all the different types of graphs they were teaching this year. Mr. Aldrin considered this to be progress toward integration because it was the first time the mathematics teachers, aside from Mr. Armstrong, had offered information concerning their lesson plans—plans that could affect the science teachers' sequencing of their own units that involved graphical representations of data.

In addition to these general changes that affected all the seventh- and eighth-grade mathematics and science teachers at Kennedy Middle School, both Mr. Armstrong and Mr. Aldrin reported specific changes they had personally undergone in working toward integrating their mathematics and science teaching. During his interview Mr. Armstrong explained that he had taught mathematics out of context for 20 years, but now that he has been afforded the opportunity to teach science, "I'll never teach math the same way again"! While he admits he had recognized problems with teaching mathematics in isolation for quite some time, his teaching of the plant diversity index in one of his science classes this year provided him with a concrete example of the benefits to students when teaching mathematics and science in an integrated fashion. He continued by explaining that in the past he has frequently taught a mathematics unit concerning measurement. This year, while he taught biology concepts using microscopes, he learned how to teach measurement concepts in a more meaningful way. In his future mathematics teaching he anticipates embedding the mathematical ideas concerning measurement in scientific contexts. Mr. Armstrong said his experience this year teaching science has rejuvenated his teaching of mathematics, and spoke passionately about his recommendation that every mathematics teacher should teach science. Mr. Armstrong experienced a renaissance of sorts. He explained that science is so much fun to teach that he would now like to teach science full-time (personal communication, November 14, 1995).

Mr. Aldrin reported two changes to his science instruction as a result of working closely with Mr. Armstrong. First, he reported that prior to their collaboration he would typically have students work in groups to conduct scientific investigations, and then base the conclusion of that investigation on just the data their group had generated. In part due to his collaboration with Mr. Armstrong, Mr. Aldrin now requires students to share their results with other groups of students, groups within their own class and groups in Mr. Aldrin's other science classes. In this way, Mr. Aldrin is having students work with larger sets of data. Second, he is incorporating more sophisticated mathematics into his laboratory investigations. While Mr. Aldrin credits the move toward integration for changing his instruction to include more data and to include more higher-level mathematics, perhaps the most significant change concerns his view of himself as a teacher of science and mathematics, not just a teacher of science. He reports that this has prompted him to assume partial responsibility for students' mathematical achievement, whereas in the past he considered this to be only the responsibility of the mathematics teachers.

Implications for Teaching and Teacher Education

This empirical study of two cases of middle school integrated mathematics and science shed light on several issues involving teaching and teacher education. Three specific implications will be discussed: (1) factors influencing the transition from separate to integrated instruction; (2) teacher preparation for effective integrated mathematics and science teaching; and (3) the way that integration of mathematics and science requires and creates different conceptions of these disciplines.

Both sets of teachers identified several factors that they considered crucial in their moving from a separate to an integrated approach to mathematics and science instruction. Table 1 summarizes the important factors, from the perspective of the teachers who participated in this study, that affected their being able to move toward an integrated approach to mathematics and science teaching and learning. These findings are supported by research reported by Francis and Underhill (1996), Wicklein and Schell (1995), Oja et al. (1995), Bransford and the Cognition and Technology Group at Vanderbilt (1994), and Jacobs (1989).

Table 1
Teachers' Perceptions of Factors Affecting Curricular Integration

Factors that Facilitate Integration of Mathematics and Science

- strong collegial support
  - similar professional goals
  - similar personal characteristics
  - similar beliefs about curriculum and pedagogy

- strong and flexible administrator support for team teaching
  - scheduling of classes
  - proximity of classrooms
  - scheduling of students
  - joint planning time

- financial support
  - acquisition of materials
  - professional development

Factors that Limit Integration of Mathematics and Science

- time
  - coordination of students
  - combined disciplinary content
  - planning for instruction as a team
  - coordination of student assessments

- availability of instructional models

- availability of appropriate curricular materials

- system-wide achievement expectations

It is important for administrators, teacher educators, curriculum developers, and policy makers to understand, and not minimize, these factors that facilitate or limit the integration of disciplinary content within the middle school curriculum. Teaching mathematics and science in an integrated fashion is a radical departure from the fragmented approach to teaching and learning that currently typifies the middle school environment. An integrated approach to teaching and learning middle school mathematics and science requires teachers to convince their administrators that the potential benefits resulting from integration outweigh the risks, requires teachers to generate their own instructional models and curricular materials, and requires teachers to seek external sources of funding. Ms. Clark, Mr. Lewis, Mr. Armstrong, and Mr. Aldrin are anomalies—they all have been recognized for their exemplary teaching practices, and they all hold strong convictions that children learn best when the curriculum is integrated. Hence, these four teachers were committed to, and able to, overcome all of these barriers. Unless there is a fundamental shift in how the goals of the middle school curriculum are conceptualized, integration of mathematics and science is well outside the reach of most teachers.

The second set of implications for this study concerns the preparation of middle school mathematics and science teachers. It is hypothesized that middle school teachers who understand the connections between mathematics and science at a deep, as opposed to a superficial level, and who can teach these disciplines in an integrated fashion, must have strong content knowledge and pedagogical content knowledge in both mathematics and science. Since many states do not currently have a middle school certification option, many middle school teachers are prepared as elementary school generalists. As such, they are ill-equipped for the task of teaching middle school integrated mathematics and science. However, there are several NSF-funded Collaboratives for Teacher Preparation which are charged with the task of producing a cadre of upper elementary and middle school teachers who can provide exemplary mathematics and science instruction and understand the connections between mathematics and science. It will be interesting to examine the school environments where these new teachers will be placed to see whether they are conducive to their taking advantage of their specialized preparation in mathematics and science.

With an eye toward informing teacher preparation programs, this researcher asked the participants in this study for their recommendations regarding preparation for teaching mathematics and science in an integrated fashion at the middle school level. Mr. Lewis and Mr. Aldrin strongly believe that teacher preparation programs that aim to produce teachers who can teach mathematics and science, and who understand the connections between these disciplines, ought to require preservice teachers to make extensive visits to classrooms with exemplary (or master) teachers who teach these disciplines in an integrated fashion. By doing so, preservice teachers will have firsthand knowledge of the complexities and classroom realities when teaching integrated mathematics and science. Mr. Lewis pointed out that there are only a few teachers who try to fully integrate mathematics and science, which limits the feasibility of this idea. Mr. Armstrong's recommendation for programs that prepare teachers of integrated mathematics and science is for an increased focus on preservice teachers' participation in labs, both math labs and science labs, and for a decreased focus on preservice teachers' learning about methods for teaching mathematics and science. Mr. Armstrong thinks that preservice teachers' engagement in mathematics and science labs will foster their understanding of the connections between these disciplines.

One final implication of this study regards the conceptualization of mathematics and science in the school curriculum. In an integrated approach to instruction, mathematics class is very often typified by student engagement in activities whereby they collect data which is then analyzed in some mathematical fashion. This approach places a stronger emphasis upon mathematical *tools* that are used in scientific investigations. Examples of these tools include measurement, proportions, and graphing—topics that have traditionally been de-emphasized in the school mathematics curriculum. An increased focus on these topics might supplant other mathematics content that is more abstract and not directly applicable to scientific investigations. In extreme cases, this might result in the study of mathematics only in an elementary or superficial sense, as opposed to the study of patterns and abstract generalizations. The conceptualization of science, too, may shift as a result of integrating mathematics and science in the school curriculum. For instance, teaching these two disciplines in an integrated fashion may require resequencing of certain topics in the curriculum. The resequencing of science content seems less arduous than resequencing mathematics topics because mathematics generally proceeds in a deductive fashion in the school curriculum. For instance, mathematics teachers do not teach fractions and then teach students about whole numbers, but a biology teacher could provide instruction on feet and then the head, or instruction on the head and then on feet, without apparent disruption. Furthermore, the science curriculum is better suited to resequencing because the different disciplines within the sciences are somewhat disjoint. Thus, integration may serve to shift emphasis of some topics within the mathematics and science curricula, and shift the sequencing of some topics within the mathematics and science curricula. This may result in a shift in what it means to know mathematics and science, which may necessitate a rethinking of the structure of the mathematics and science curricula and goals therein.

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