Analysis on the Theoretical Models Related to the Integration of Science and Mathematics Education: Focus on Four Exemplary Models

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Abstract: The purposes of this study were to inform the exemplary models of integrated science and mathematics and to analyze and discuss their similarities and differences of the models. There were two steps to select the exemplary models of integrated science and mathematics. First, the second volume (Berlin & Lee, 2003) of the bibliography of integrated science and mathematics was analyzed to identify the models. As a second step, we selected the models that are dealt with in the School Science Mathematics journal and were cited more than three times. The findings showed that the following four exemplary theoretical models were identified and published in the SSM journal: the Berlin-White Integrated Science and Mathematics (BWISM) Model, the Mathematics/Science Continuum Model, the Continuum Model of Integration, and the Five Types of Science and Mathematics Integration. The Berlin-White Integrated Science and Mathematics (BWISM) Model focused an interpretive or framework theory for integrated science and mathematics teaching and learning. BWISM focused on a conceptual base and a common language for integrated science and mathematics teaching and learning. The Mathematics/Science Continuum Model provided five categories and ways to clarify the extent of overlap or coordination between science and mathematics during instructional practice. The Continuum Model of Integration included five categories and clarified the nature of the relationship between the mathematics and science being taught and the curricular goals for the disciplines. These five types of science and mathematics integrations described the method, type, and instructional implications of five different approaches to integration. The five categories focused on clarifying various forms of integrated science and mathematics education. Several differences and similarities among the models were identified on the basis of the analysis of the content and characteristics of the models. Theoretically, there is strong support for the integration of science and mathematics education as a way to enhance science and mathematics learning experiences. It is expected that these instructional models for integration of science and mathematics could be used to develop and evaluate integration programs and to disseminate integration approaches to curriculum and instruction.

Key words: Integration, Integrated science and mathematics, Model

Introduction

The field of integrated science and mathematics education has been developing for nearly a century and has flourished especially during the last few decades (Berlin & Lee, 2005; Berlin & White, 1998; Pang & Good, 2000). A number of national science, mathematics, technology education professional associations, and recently engineering education association are united in their support for the integration of science, mathematics, and/or technology (engineering) teaching and learning. The national education standards and reform documents published by the following associations support the integrative approaches on science and mathematics education: American Association for the Advancement of Science (1989, 1993, 1998), International Technology Education Association (1996, 2000), National Council of Teachers of Mathematics (1989, 1991, 1995, 2000), National Research Council (1996), National Science Teachers Association (1992, 1997), and National Academy of Engineering (2002, 2004, 2005).

The following excerpts from science educational documents attest to the significance and importance of this compilation of the literature related to integrated science and mathematics in school education. These

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documents explain the interrelated nature of science and mathematics along with implications for teaching and learning.

> 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. (National Research Council, 1996, p. 214)

> It is the union of science, mathematics, and technology that forms the scientific endeavor and that makes it so successful. Although each of these human enterprises has a character and history of its own, each is dependent on and reinforces the others. (American Association for the Advancement of Science, 1993, p. 3)

A similar position is reflected in the national standards promoted by the mathematics education community. Opportunities for students to understand, experience, and apply mathematics in real-world contexts outside of mathematics are crucial to the document entitled *Principles and Standards for School Mathematics* (National Council of Teachers of Mathematics, 2000).

> A coherent curriculum effectively organizes and integrates important mathematical ideas so that students can see how the ideas build on, or connect with, other ideas, thus enabling them to develop new understandings and skills (p. 15).

> The opportunity for students to experience mathematics in a context is important. Mathematics is used in science, the social sciences, medicine, and commerce. The link between mathematics and science is not only through content but also through process. The processes and content of science can inspire an approach to solving problems that applies to the study of mathematics…School mathematics experiences at all levels should include opportunities to learn about mathematics by working on problems arising in contexts outside of mathematics. These connections can be to other subject areas and disciplines as well as to students' daily lives (pp. 65-66).

This national mathematics standard in the U.S. that guides both state curriculum frameworks and local courses of study affirms the significance of the integration of science and mathematics education. According to Berlin and Lee (2005), the number of integrated science and mathematics documents since 1970s has been dramatically increased, and the trend seems to be continuing into the 21st century. Recently, Science, Technology, Engineering, and Mathematics Education (STEM) is a new integrated approach that has indeed gained momentum in the U.S. Despite the documents related to the integration of science and mathematics that have been published through 1990s yielding an impressive and revealing trend toward the integration of certain subjects, there have been few studies to explore the models of integrated science and mathematics. In particular, there is no research that analyzes the models of integrated science and mathematics to provide implications for science and mathematics teaching and learning.

This exploratory study is designed to inform the exemplary models of integrated science and mathematics and to compare the models. The specific research contents to be addressed in this study are as follows:

1. Explore major theoretical models related to the integration of science and mathematics education.
2. Analyze and discuss their similarities and differences of the models.

Method

There were two steps to select the exemplary models of integrated science and mathematics. First, I analyzed the second volume of the bibliography of integrated science and mathematics(Berlin and Lee, 2003). The bibliography included 402 journal articles and documents related to integrated science and mathematics teaching and learning. This bibliography has been prepared for classroom teachers, teacher educators, curriculum reformers and developers, and educational researchers interested in the exploration of the topic of integrated science and mathematics teaching and learning. In addition, Berlin and Lee (2005) conducted a historical and categorical analysis on the integration of science and mathematics teaching and learning literature based on the bibliography analyzed by Berlin and Lee (2003).

As a second step, we selected the models that are dealt with in the School Science and Mathematics (SSM) journal and were cited more than three times. It could imply that the models were reviewed and revised by many experts and educators. The SSM journal, the official journal of the School Science and Mathematics Association, has served as a fundamental source for trends and issues of integrated approaches in mathematics and science education during the last century. SSM has taken the lead in presenting science and mathematics educators with theoretical models for integration of mathematics and science (Berlin, 1991; Berlin & White, 1994).

A careful review of the second volume (Berlin and Lee, 2003) of the bibliography of the integrated science and mathematics and journal articles resulted in a list of models of integrated science and mathematics. All four exemplary theoretical models we selected were identified from the SSM journal.

- Berlin-White Integrated Science and Mathematics (BWISM) Model
- Mathematics/Science Continuum Model
- Continuum Model of Integration
- Five Types of Science and Mathematics Integration

In order to discuss their similarities and differences, the four models were divided into two groups according to their nature: Group A (Mathematics/Science Continuum Model, and Continuum Model of Integration), and Group B (the Berlin-White Integrated Science and Mathematics Model, and the Five Different Meanings of Integration of Science and Mathematics). Several differences and similarities within groups were explained on the basis of the analysis of the content and characteristics of the models.

Findings

1. The Berlin-White Integrated Science and Mathematics Model

The Berlin-White Integrated Science and Mathematics Model (BWISM) proposed by Berlin & White (1994), is an interpretive or framework theory and is designed to "provide a conceptual base and a common language that advances the research agenda, to serve as a template for characterizing current resources, and to guide in the development of new materials related to integrated science and mathematics teaching and learning" (Berlin & White, 1998, p. 504).

The BWISM includes six aspects: (a) ways of learning, (b) ways of knowing, (c) process and thinking skills, (d) content knowledge, (e) attitudes and perceptions, and (f) teaching strategies. All six aspects of the BWISM model are based on constructivist ideas. As Berlin and White (1995a) mentioned, these aspects are not "isolated or exclusive of one another…in various combinations, can serve as a basis to generate operational definitions and comparable research" (p. 23). In other words, these six aspects will be considered in constant interplay when educators use them to define, teach, learn, develop, and assess integration of mathematics and science.

The specific explanations and examples of the BWISM aspects are described in Table 1.

In addition, the BWISM template developed by Berlin and White (1999) can help teachers to characterize an integrated mathematics and science activity and to develop integrated mathematics and science curriculum and instructional materials (Table 2). According to Berlin and White (1999), the template highlights the characteristics of an integrated activity with respect to five of the BWISM aspects: ways of knowing, content knowledge, process and thinking skills, attitudes and perceptions, and teaching strategies. One of the BWISM aspects, ways of learning, is not included in the template because it is a rationale supportive of the other aspects.

2. Five types of science and mathematics integration

Davison, Miller, and Metheny (1995) present five different meanings of integration of science and mathematics: discipline specific integration, content specific integration, process integration, methodological integration, and thematic integration. First, the discipline specific integration is composed of more than two different branches of mathematics or science (Table 3). Davison *et al.* (1995) described that "this type of integration requires a problem where students reach an informed decision based upon data analysis from all the disciplines and their use of critical thinking and problem solving skills" (p. 227). Students can learn that branches of mathematics (Algebra, Geometry, and Measurement) as well as the branches of science (Life Science and Health science) are interrelated. Those sciences and mathematics should be infused perfectly. However, Davison et al. (1995) indicated "there are times when the branches of mathematics or science must be taught separately so that students know the basic concepts, skills, and procedures" (p. 227).

Second, content specific integration combines the existing programs in science and mathematics with an existing curriculum objective found in both fields. In other words, this approach to integrating curriculum conforms to the previously developed curriculum, infusing the objectives form each discipline. Davison *et al.* (1995) mentioned that "not all mathematics and scientific concepts can be integrated. Basic mathematical and scientific concepts and processes may need to be taught first, and sometimes separately" (p. 228).

Third, process integration is more concerned with the process of learning. The approach to curriculum is usually through the use of real-life activities and experiments. Students can learn science processes as well as needed mathematical skills.

Fourth, methodological integration implied that "good science methodology is integrated in good mathematics teaching" (Davison, *et al.*, 1995, p. 228). They also described that "the methodological approach to the integration of scientific methods clearly focuses on experimental science…Students will investigate issues in both science and mathematics using related strategies such as inquiry, discovery, and the learning cycle" (p. 229).

Finally, thematic integration integrates mathematics, science, and other possible disciplines around a central theme. Miller and Davison (1998) stated "the thematic approach begins with a theme, which then becomes the medium for all the disciplines to interact…The purpose is to provide relevancy to the learner regarding the school disciplines and the interaction of the natural world" (p. 8).

3. Mathematics/Science Continuum Model

Huntley (1998) proposed the Mathematics/Science Continuum Model that is "offered as a means to clarify the extent of overlap or coordination between the disciplines during instructional practice" (p. 321). In this model there are five categories: Mathematics for the

Table 1

Six Aspects of the BWISM (Berlin & White, 1998, pp. 503-504)

Aspects	Description
Ways of learning	Integration can be based on how students experience, organize, and think about science and mathematics. Based on a constructivist/neuropsychological perspective or rationale, students must do science and mathematics and be actively involved in the learning process.
	■ Focused on the perspectives of students (their experience, belief, pre-existing concepts, etc.) ■ Student-centered learning (Meaningful learning)
Ways of knowing	Integration of science and mathematics learning can reinforce the cyclical relationships between inductive-deductive and qualitative-quantitative views of the world. In science and mathematics, new knowledge is often produced through a combination of induction and deduction. For this discussion, induction means looking at numerous examples to find a pattern (qualitative) that can be translated into a rule (quantitative). The application of this rule in a new context is deduction.
	■ Inductive and/or deductive ways of knowing ■ Understanding of the relationships and connections between scientific and mathematical ways of knowing
Process and thinking skills	Integrated science and mathematics can develop processes and skills related to inquiry, problem-solving, and higher-order thinking skills. Integration of science and mathematics can focus on ways of collecting and using information gathered by investigation, exploration, experimentation, and problem solving. Skills such as classifying, collecting and organizing data, communicating, controlling variables, developing models, estimating, experimenting, graphing, inferring, interpreting data, making hypotheses, measuring, observing, recognizing patterns, and predicting are representative of this aspect.
	■ Processes and skills related to scientific and mathematical inquiry, problem-solving, and higher-order thinking skills
Content knowledge	Science and mathematics can be integrated in terms of content that is overlapping or analogous. The examination of the concepts, principles, laws, and theories of science and mathematics reveal ideas that are unique to each discipline as well as ideas that overlap or are analogous (e.g., the fulcrum of a lever and the mean of a distribution).
	■ Perspective of the overlapping or analogous conceptual knowledge in mathematics and science ■ Numbers and operations; Patterns, Functions, and Algebra; Geometry and Spatial Sense; Measurement; Data Analysis, Statistics and Probability; Change; Conservation; Models; Patterns; Scale; Symmetry; Systems
Attitudes and perceptions	Integration can be viewed from what children believe about science and mathematics, their involvement, and their confidence in their ability to do science and mathematics. Similarities and differences related to scientific and mathematical attitudes/perceptions or 'habits of mind' can be identified. The values, attitudes, and ways of thinking shared between science and mathematics, basing decisions and actions on data, a desire for knowledge, a healthy degree of skepticism, honesty and objectivity, relying on logical reasoning, willingness to consider other explanations, and working together to achieve better understanding.
	■ Dynamic nature of mathematics and science; Habits of minds/dispositions; Reasoning/Date-based decisions
Teaching strategies	Integration can be viewed from the teaching methods valued by both science and mathematics educators. Integrated science and mathematics teaching should include a broad range of content, provide time for inquiry-based learning, afford opportunities to use laboratory instruments and other tools, provide appropriate uses of technology (e.g., calculators and computers), include an embed assessment within instruction, and maximize opportunities for successful connections between science and mathematics.
	■ A variety of science and mathematics teaching methods ■ Alternative Assessment; Cooperative Learning; Educational Technology; Inquiry-based; Multiple Representational modes; Problem solving; Mathematics manipulatives, Science equipment

Table 2

BWISM Template (Berlin & White, 1999)

I. WAYS OF KNOWING
Induction; Deduction; Inductive-Deductive Cycle
II. CONTENT KNOWLEDGE
Number and Operation; Patterns, Functions, and Algebra; Geometry and Spatial Sense; Measurement; Data Analysis, Statistics and Probability; Change; Conservation; Models; Patterns; Scale; Symmetry; Systems
III. PROCESS AND THINKING SKILLS
Classifying; Collecting and Organizing Data; Communicating; Controlling Variables; Developing Models; Defining Operationally; Estimating; Experimenting; Graphing; Hypothesizing; Inferring; Interpreting Data; Measuring; Observing; Predicting; Recognizing Patterns
IV. ATTITUDES AND PERCEPTIONS
Dynamic Nature of Mathematics and Science; Habits of Minds/Dispositions; Reasoning/Data-Based Decisions
V. TEACHING STRATEGIES
Alternative Assessment; Cooperative Learning; Educational Technology; Inquiry-Based; Multiple Representational Modes; Problem Solving; Mathematics Manipulatives; Science Equipment

Table 3

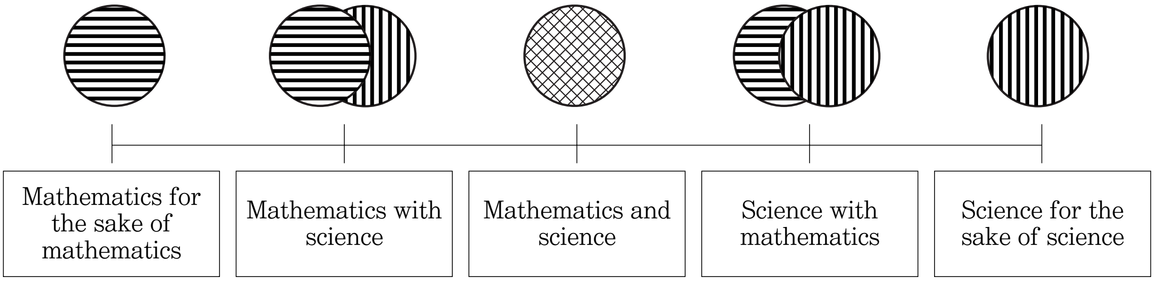
Five Types of Mathematics and Science Integration (Davison, Miller, & Metheny, 1995)

Type	Description
Discipline Specific Integration	An activity that includes two or more different branches of mathematics or science.
	Example: This integration type might include activities involving Algebra and Geometry in mathematics and activities infusing Biology, Chemistry, and Physics in science.
Content Specific Integration	An activity is developed on the basis of an existing curriculum objective from mathematics and one from science.
	Example: The content objective for mathematics is measurement, and the science content objective is the study of dinosaurs.
Process Integration	An activity or experiment includes a variety of process/skills in science and mathematics.
	Example: In the AIMS activity What's in the bag?, the science processes of identifying and controlling variables, hypothesizing, interpreting, and predicting are integrated with the mathematical skills of averaging, graphing, and estimating.
Methodological Integration	Good science methodology is integrated in good mathematics teaching. Integration of scientific methods focuses on experimental science and mathematics teaching.
	Example: Mathematics developed under the constructivist theory using science discovery and inquiry teaching techniques and building on prior knowledge characterize another form of integration.
Thematic Integration	An activity/lesson uses a theme that can provide interrelated concepts of science and mathematics.
	Example of theme: Shark; Oil spills; The reintroduction of the wolf into Yellowstone National Park

sake of mathematics, Mathematics with science, Mathematics and science, Science with mathematics, and Science for the sake of science (Figure 1). The ends of the model focus on separate disciplines (either of science or mathematics). Approaching to the middle section 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" (p. 321).

4. Continuum Model of Integration

Lonning and DeFranco (1997) proposed the Continuum Model of Integration (Figure 2). This model focuses on characterizing "the nature of



Category	Description
Mathematics for the sake of mathematics	A mathematics course that presents mathematics as a formal system
Mathematics with science	A mathematics course in which science (content and/or methods) is used to establish problem context and relevance
Mathematics and science	Mathematics (content and methods) and science (content and/or methods) course in which these two disciplines play synergistic roles in explaining the world
Science with mathematics	A science course which emphasizes mathematics (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

Fig. 1 *Mathematics/Science Continuum*

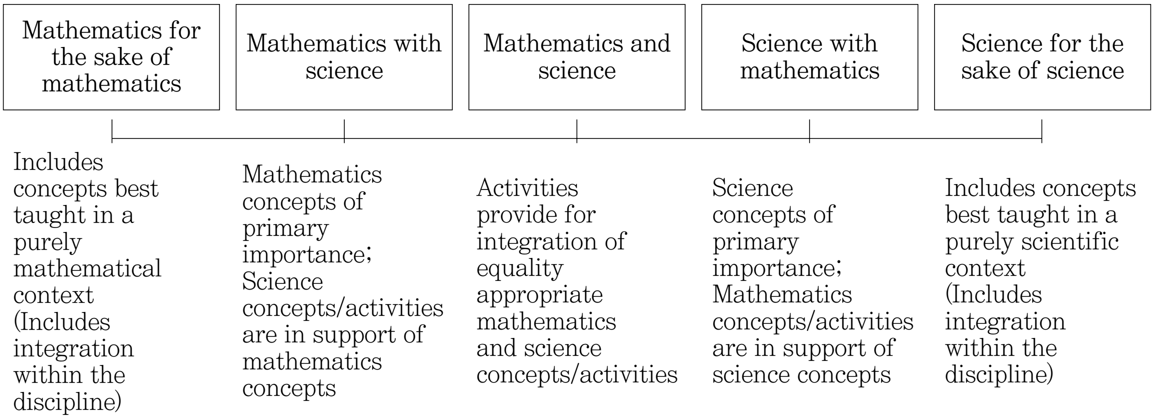


Fig. 2 *Continuum Model of Integration*

the relationship between the mathematics and science being taught and the curricular goals for the disciplines" (p. 212). The model includes five categories: Independent Mathematics, Mathematics Focus, Balanced Mathematics and Science, Science Focus, and Independent Science.

According to Lonning and DeFranco (1997), "content that meets the curricular goals and objectives for a particular grade level in one of the disciplines (mathematics or science), but includes concepts from the other disciplines that are not at the same grade level are classified as mathematics focus or science focus on the continuum. When the mathematics and science content are "both part of the curriculum for a particular grade level and the instruction is delivered in a meaningful way, the activities created are classified as 'balanced' on the continuum" (p. 213). The ends of the model represent only one independent discipline (mathematics or science) that includes integration within one discipline.

5. Differences and Similarities

As described in the method section, four models were divided into two groups according to the nature of models: Group A (Mathematics/Science Continuum Model and Continuum Model of Integration), and Group B (the Berlin-White Integrated Science and Mathematics Model and the Five Different Meanings of Integration of Science and Mathematics). The differences and similarities within groups were explained in this section.

Firstly, two models of Group A were based on a five-part continuum. Even though the two models used different labels, their models included the same five-category structure (see Figures 1, 2). Huntley's (1998) model is very similar to the Lonning and DeFranco (1997) model. As Huntley (1997) observed, participants at the 1967 Cambridge Conference used the following five categories for describing various interactions between mathematics and science: 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. Huntley (1997) used two of the same labels with the five categories proposed in 1967. Both models tried to transform the five categories presented in 1967 into more continuous categories in order to explain the extent of integrated mathematics and science. Therefore, the fundamental "continuum" idea is shared by each theory.

According to Huntley (1998), a crucial difference exists at the center of the two continua. In the Lonning and DeFranco model, the middle section represents activities in which there is equal treatment of the separate disciplines, mathematics, and science. By contrast, in the Mathematics/Science Continuum, the middle section indicates integrated mathematics and science, where the disciplines mathematics and science interact and support each other. In this sense, there is more than just equal treatment of the two disciplines-there is a synergistic union of the two disciplines, the result being an activity or curricular unit in which the interactions between the disciplines result in students learning more than just the mathematics and science content contained therein" (p. 322). Furthermore, the Continuum Model of Integration (Figure 2) distinguishes between the various categories of integrated mathematics and science based on whether the material that is presented to students is at the appropriate grade level, whereas in the Math/Science Continuum (Figure 1) this division is based on whether students are learning new content from each of the disciplines irrespective of grade level (Huntley, 1997).

Second, the two models of Group B emphasize a broad range of aspects to describe integration of science and mathematics more than the two continuum models of Group A. In other words, while the two models of Group A emphasize a one-dimensional content-based model of integrated curriculum, the two models of Group B concentrate on a multi-dimensional model. These models clarify and give a more detailed description of the nature of an integrated curriculum. BWISM's six aspects can be used as a very wide scale template or basis for characterization of science and mathematics integrated resources and as guidelines for the development of new integrated materials. BWISM provides a broad range of aspects to provide some clarification of the characteristics for defining, implementing, and evaluating integration. Furthermore, the five types of science and mathematics integration presented by Davison et al. (1995) attempt to describe the method, type, and instructional implications of five different approaches to integration. These five categories focus on clarifying various forms of integrated science and mathematics education.

There are some similarities between the five types and the BWISM Model and Template. For example, 'Process Integration' includes almost the same scientific and mathematical process skills as 'Process and Thinking Skills' in the BWISM template. Davison et al. (1995) explained that this approach to integrating curriculum is through the use of real-life activities in the classroom. 'Process Integration' was identified by instructional activity designed for students to experience the processes of science and mathematics. The 'Methodological Integration' can be characterized by using science and mathematics teaching techniques and strategies as well as constructivist principles. The main contents in two aspects of the BWISM Model, 'Learning' and 'Ways of Knowing,' are similar to the ideas of the Methodological Integration. The teaching strategies category of BWISM template (e.g., alternative assessment, inquiry based, and problem solving) are almost same components with the teaching techniques and strategies in the 'Methodology Integration.' On the other hand, the BWISM template does not include 'Thematic Approach' in its integration approach directly. However, 'Thematic Approach' can be indirectly related to all six aspects of the BWISM template. Both models give teachers and researchers a uniform means to describe the integration of science and mathematics in a way that can be universally understood.

Summary and Implications

Summary

There is strong theoretical support for the integration of science and mathematics education as a way to enhance those two disciplines' learning experiences and to improve student understanding of how the content is related to their real-world applications. The major purpose of this study was to explore the exemplary models of integrated science and mathematics and inform some similarities and differences of the selected models. Moreover, the summary of the findings and the implications for the integration of science and mathematics education and integrated science education in Korea will be described in this section.

The Berlin-White Integrated Science and Mathematics (BWISM) Model was introduced in 1994, and its content appeared in several journals (Berlin & White, 1994; 1995a, 1995b, 1998; 1999; Berlin & Lee, 2005; Lee et al., 2010). BWISM was an interpretive or framework theory. It focused on a conceptual base and a common language for integrated science and mathematics teaching and learning.

The Mathematics/Science Continuum Model was proposed by Huntley (1997, 1998) and provided five categories and ways to clarify the extent of overlap or coordination between science and mathematics during instructional practice. The Continuum Model of Integration presented by Lonning and DeFranco (1997) and Lonning et al. (1998) included five categories and clarified the nature of the relationship between the mathematics and science being taught and the curricular goals for the disciplines. Five types of science and mathematics integration were introduced in several journals (Davison et al., 1995; Miller, et al., 1993; Miller & Davison, 1998). These articles described the method, type, and instructional implications of the five different approaches to integration. The five categories focused on clarifying various forms of integrated science and mathematics education.

Implication for Integration of Science and Mathematics Education

The instructional models for the integration of science and mathematics can be used to develop and evaluate integration programs and projects and to disseminate integration approaches to curriculum and instruction. Many studies support the integration of science and mathematics education (Brasell, 1987; Burrill & Kennedy, 1997; Friend, 1985; Foss & Pinchback, 1998; Hurley, 1999; LaPorte & Sanders, 1993, 1996; Meier *et al.*, 1998; Pang & Good, 2000; Ross & Hogaboam-Gray, 1998; Stevens & Wenner, 1996; Venville *et al.*, 1998). These studies make it clear that the integration of science and mathematics cannot only provide less fragmented and disconnected knowledge for students, but also provide effective opportunities for students to construct valuable knowledge on the basis of their pre-existing knowledge, believes, and experiences. In addition, the integration of science and mathematics had a positive impact on students' achievement and affective domains (e.g, interest, attitude, confidence, preference for science and mathematics, and so on) (Austin *et al.*, 1997; Berlin & Hillen, 1994; Brasell, 1987; Burrill & Kennedy, 1997; Friend, 1985; Hurley, 1999; Pang & Good, 2000; Ross & Hogaboam-Gray, 1998; Roth, 1992, 1993; Venville *et al.*, 1998).

However, there are still many barriers related to the integration of science and mathematics. The most important factor for successful integration is the teacher. Teachers who teach in integration classrooms should be more knowledgeable, skillful, and resourceful in being able to guide students' explorations, experiences, and construction of knowledge. As Lehman and McDonald (1988) and Lehman (1994) investigated, many teachers, however, are still unaware of curriculum materials designed toward the integration of science and mathematics. Also, teachers who teach an integrated curriculum do not possess enough knowledge about the connections between two disciplines. Moreover, they lack the opportunities to improve their skills and knowledge and to learn about teaching integration.

Therefore, more research concerning pre-service education, professional development, opportunities for teacher education, production of instructional materials, and renovation of current teacher education programs for integration need to be conducted. In this sense, we strongly support Lehman's (1994) recommendations for action. Educators, administrators, and researchers need to 1) explore alternative models for both pre-service and in-service education for the integration of mathematics and science education, 2) provide an opportunity for teachers to teach integrated mathematics and science lessons during supervised field experiences, 3) develop teachers' understanding of integrated instruction and curriculum and of the recommendations for science and mathematics content contained within national standards, and 4) develop science and mathematics community members' awareness for the purpose of integrating science and mathematics education as an educational reform component while developing their support for implementing and disseminating this educational change.

Implication for Integrated Education in Korea

The Korean national curricula have been reformed in 5-10 year cycles since 1948. The 2009 revised national curriculum was implemented in this year, 2011. Throughout the history of the revision of the curriculum, some evidence for integration can be found from the fourth national curriculum (1981-1987) (KEDI, 1983). The fourth national curriculum was comprised of new integrated curriculum for grades 1 and 2. The Ministry of Education (MOE) offered the integrated subject matters: 'Intelligent Life,' 'We are the first graders,' 'Pleasant Life,, and 'Disciplined Life.' For example, Seulgiroun Saenghwal (meaning, "being a smart in our life" or "intelligent life") as a subject matter included science and mathematics. Mathematics was used as a tool and process skill when students explored scientific knowledge and natural phenomena through observation and/or simple experiment (Yu, 1983). This curriculum structure for first and second graders has been continued through the current national curriculum.

In addition to this effort, the Korean government offered a new integrated science course for the secondary level from the fifth national curriculum (Ministry of Education, 1997). However, the contents of the science textbook just included four different science disciplines: Physics, Chemistry, Biology, and Earth Science. The content areas did not integrate or connect to one another. Previously, high school students had four different science teachers with each one teaching integrated science according to the nature of the textbook's unit. There has been a discrepancy between the government purpose (and national curriculum) and classroom practice. Currently, the 2009 revised national curriculum offers "Infused Science" for high school students (Ministry of Education, Science and Technology, 2009).

It seems more difficult to implement integrated curriculum at the secondary level than at the elementary level. There are several reasons for this. First, the national educational purpose and policy for the secondary level education does not include any content for the integration of science and mathematics. In other words, policymakers and researchers who work for national education have not yet recognized the importance of integration. Therefore, changing the attitudes of both administrators and policymakers is the most difficult part of implementing an integrated curriculum in Korean secondary level school education.

Second, current traditional boundaries between disciplines have been supported for secondary school education since 1948. Even though the Ministry of Education, Science and Technology (MEST) has tried to offer an integrated (infused) science, science education communities did not accept these changes very well. Most teachers felt each discipline has been taught very well separately. In the case of the integrated science subject, what the attempt to integrate science curriculum in the past has lacked was a conceptual focus as well as empirical and theoretical research to support integrated science. In Korea, a new logical focus and research for integration are strongly needed for the national science curriculum.

Third, in order to implement the integration of science and mathematics education, MEST should pay full attention to promoting and improving other educational components such as the school system, the college entrance examination system, pre-service and in-service programs for science and mathematics teachers, the development of instructional materials, and continuous curriculum research. For example, most science teachers have no experience in the mathematics class or opportunities to collaborate with a mathematics teacher because there is no in-service education program. Moreover, emphasis of integrated science and mathematics might be better placed on integrating instructional methodologies rather than on integrating content, especially at the secondary level in Korea.

In contrast, Korea has a different educational situation at the elementary school level. As Steen (1994) believed, "elementary school is an obvious exception to many of my concerns about philosophy, coherence, and instruction…it should be possible to develop a good coherent joint curriculum in science and mathematics…" (p. 11). Moreover, several findings indicated that integrated science and mathematics programs had positive impacts on elementary school level students' achievement and performance (Goldberg & Wagreich, 1991; Lehman, 1994).

As mentioned above, an integrated science and mathematics curriculum has been used for grades 1 and 2 since 1981 in Korea. The basic reason why an integrated curriculum began at this level was that one elementary teacher covered all school subjects. Elementary pre- and in-service programs are relatively well organized, which eases the implementation of an integrated curriculum more than at the secondary level. For instance, university students who want to be an elementary school teacher are required to obtain course credits regarding all school subject areas, even music and fine arts. This fact implies that elementary pre-service education has a good condition and possibility for making appropriate and effective connections between science and mathematics teaching and learning.

However, we can also find several barriers that hinder the integration of science and mathematics at the elementary school level (MOE, 1997). First, the Korean government makes and provides one standardized textbook that includes integrated subjects for elementary school. This centralized education system prevents development of integration materials and resources. In the United States, a number of notable curriculum programs and projects regarding integrating science and mathematics have been produced since the 1970s: the Minnesota Mathematics and Science Teaching Project (MINNEMAST), Unified Science and Mathematics for Elementary Schools (USMES), Activities Integrating Math and Science (AIMS), Great Explorations in Math and Science (GEMS), Teaching Integrated Mathematics and Science (TIMS), The Voyage of the Mimi and The Second Voyage of the Mimi, and School Science and Mathematics Integrated Lessons (SSMILES) (Berlin & White, 1995a). Compared with these cases in the United States, elementary teachers in Korea have very limited resources, curriculums, and instructional materials for integrated education. They just follow the direction of the limited instructional materials developed by MOE.

Second, there are only a few studies regarding theoretical integration in secondary level identified Korean literature (Choi and Choi, 1999; KEDI, 1983; Son & Lee, 1999; Lee *et al*., 2010). The lack of theoretical research indicated little change of Korean elementary school toward integration education. In fact, it is difficult to discuss the role of integrated science and mathematics education in Korea without findings from the research. However, the educational situation is now changing. Even though integrated science and mathematics as a subject has not been accepted in other elementary school levels, there is a growing awareness that integration of science and mathematics works well in everyday life for younger students, that school education needs more emphasis on connecting science to other school subjects, and MEST needs to provide new perspectives and theoretical models for improved education. Evaluating the existing integrated curriculum, showing empirical evidence, increasing educators' awareness, understanding and support, and developing integrated resources are important steps in current school education in Korea for disseminating and implementing the integrated curriculum.

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