Mathematics and Science Together: Establishing the Relationship for the 21st Century Classroom

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Overview of the Literature

The field of integrated mathematics and science education is not new. Since the beginning of the 20th century, the integration of mathematics and science education has been suggested as a promising path toward improved student understanding of, performance in, and attitude toward both subject areas. Having spent over 15 years acquiring and reviewing the literature related to the integration of mathematics and science education has resulted in the amassing of over 600 citations. To characterize this robust body of literature, five categories were chosen: Curriculum, Instruction, Research, Curriculum-Instruction, and Curriculum-Evaluation. A narrow definition of curriculum, i.e., the intended learnings or the outcomes of being educated, was used. Citations in the Curriculum section primarily deal with the content in a course or a group of courses or simply put "what students are taught." Instruction is the process of implementing the curriculum and deals with pedagogy, strategies, and activities. The Research section deals with theoretical models, concept papers, empirical research, and reviews of research. Two additional sections focus specifically on curriculum programs. The Curriculum-Instruction section includes instructional activities and the Curriculum-Evaluation section includes evaluation information, both related to specific curriculum programs. The initial review of the literature spanned the years 1905 through 1991 and included 555 citations (see Berlin, 1991). The years 1992 through the first six months of 1999 include an additional 210 citations (see Berlin, 1999). Clearly, the last 6 ½ years has witnessed a tremendous growth in articles focused on the integration of mathematics and science education. The number of articles published in the last 6 ½years was nearly 40% of the number of articles published in the preceding 87 years.

Returning to the section divisions, one finds a consistent pattern for nearly 100 years – approximately 50% of the documents are categorized as instructional. There is an abundance of published strategies and activities to integrate mathematics and science education. However, most of the instructional activities are primarily science activities or lessons that include mathematics-related concepts. These science activities are most often found in the journals published by the National Science Teachers Association, including *Science and Children*, *Science Scope*, and the *Science Teacher*. The science processes of classifying, collecting and organizing data, communicating, controlling variables, developing models, experimenting, inferring, interpreting data, measuring, observing, predicting, and space-time relationships are most frequently cited in the instructional literature. The most frequent mathematics concepts and skills mentioned include angular measurement, estimation, formulas and equations, fractions, functions, geometry, graphing, modeling, patterns, percentage, probability and statistics, problem solving, ratio and proportion, and variable. The mathematics concepts are sometimes but not often explicitly stated as objectives, particularly in the science-based activities. Activities or lessons related to both mathematics and science can be found in other journals, including *School Science and Mathematics* and journals published by the National Council of Teachers of Mathematics such as the *Arithmetic Teacher*, *Teaching Children Mathematics*, *Mathematics Teaching in the Middle School*, and the *Mathematics Teacher*. The aforementioned concepts, skills, and processes for mathematics and science are also often the basis for the curriculum and the instructional activities developed for specific projects, e.g., *Activities Integrating Math and Science* (AIMS); *Great Explorations in Math and Science* (GEMS); *Integrating Mathematics, Science, and Technology* (IMaST); *Minnesota Mathematics and Science Teaching Project* (MINNEMAST); *Teaching Integrated Mathematics and Science* (TIMS); and *Unified Science and Mathematics for Elementary Schools* (USMES).

As one reviews the literature by category, another interesting pattern is revealed. The Research section, including theoretical models, concept papers, and empirical research, consists of the smallest percentage of citations. For the first 87 years, only 7% of the documents were in this category. Furthermore, many of the documents included in this section were only tangentially related to integrated mathematics and science education. For example, a number of research studies related mathematics skills such as conservation, seriation, graphing ability, proportional reasoning, and spatial ability to science achievement. Since 1991, the Research section has advanced to 17% of the citations or 36 articles. Further exploration into the nature of the updated Research section suggests a grouping based on theoretical models/concept papers, empirical research, and tangentially-related empirical research. This subgrouping reveals that the number of theoretical models and concept papers related to integrated mathematics and science education represents more than half of the Research section (20 citations). Unfortunately, one still finds a critical shortage of literature focused on empirical research (12 citations; 6% of the total citations). Only 4 of the articles listed in the Research section are classified as tangentially related to integrated mathematics and science education, e.g., research relating the development of graphing skills to the use of microcomputer-based science laboratories.

Since a review of all the literature related to mathematics and science education is well-beyond the scope of this paper, the focus will be on an analysis of various theoretical models. This discussion will set the stage for the Berlin-White Integrated Science and Mathematics Model (BWISM), an interpretative or framework theory, not a normative goal-directed theory. As an interpretive or framework theory, BWISM is designed to describe or characterize the integration of science and mathematics education, not specify goals related to successful integration. Therefore, BWISM is meant to be used and interpreted by researchers and practitioners within the context of their own cognition and experience.

One has little difficulty finding proponents of mathematics and science integration. Current reform documents in the United States recommend integration of content and instruction in a changing curriculum. Documents such as *Curriculum and Evaluation Standards for School Mathematics* (National Council of Teachers of Mathematics, 1989); *Principles and Standards for School Mathematics: Discussion Draft* (National Council of Teachers of Mathematics, 1998); *Reshaping School Mathematics. A Philosophy and Framework for Curriculum* (National Research Council, 1990); *Science for All Americans* (Rutherford & Ahlgren, 1990); *Benchmarks for Science Literacy* (American Association for the Advancement of Science, 1993); and *National Science Education Standards* (National Research Council, 1996); recognize the integration of mathematics and science as a necessary component of reform.

Since mathematics is both the language of science and a science of patterns, the special links between mathematics and science are far more than just those between theory and applications. The methodology of mathematical inquiry shares with the scientific method a focus on exploration, investigation, conjecture, evidence, and reasoning. Firmer school ties between science and mathematics should especially help students' grasp of both fields. (National Research Council, 1990; pp.44-45)

Although the area of integrated mathematics and science education is not new as evidenced by writings dating back to 1905, it is complex, not well defined, and inadequately studied. The literature in the last decade has increasingly focused on defining integrated mathematics and science education through theoretical models. An earlier theoretical model, posited by the participants of the Cambridge Conference on Integration of Mathematics and Science Education held in 1967 (Education Development Center, 1970), defined five categories of interaction between mathematics and science. These categories include: math for math, math for science, math and science, science for math, and science for science. Brown and Wall (1976) fashioned these categories into a continuum consisting of mathematics for the sake of mathematics, mathematics for the sake of science, mathematics and science in concert, science for the sake of mathematics, and science for the sake of science. Recent theoretical models have used this same continuum with minor wordsmithing. For example, Lonning and DeFranco (1997) describe their continuum as independent mathematics, mathematics focus, balanced mathematics and science, science focus, and independent science. Similarly, Huntley (1998), using an interesting foreground/background analogy, suggests a continuum from mathematics for the sake of mathematics, mathematics with science, mathematics and science, science with mathematics, and science for the sake of science. Finally, Roebuck and Warden (1998) modify the Brown and Wall continuum to include math for math's sake, science-driven math, mathematics and science in concert, math-driven science, and science for science's sake. Only one recent theoretical model, the Berlin-White Integrated Science and Mathematics (BWISM) Model (Berlin & White, 1994), uniquely describes the center of the continuum, mathematics and science.

Berlin-White Integrated Science and Mathematics Model (BWISM)

The Berlin-White Integrated Science and Mathematics Model has been recognized in both the mathematics and science education communities (Berlin & White, 1994, 1995, 1998). Evolving over a period of 15 years, it reflects and combines multiple perspectives and endeavors, including empirical research, a comprehensive review of the literature, the perspectives of the mathematics and science communities, curriculum research and development projects, and valued classroom practice. With National Science Foundation support, a 1991 national level conference on the integration of mathematics and science education (Berlin, 1994; Berlin & White, 1992) further helped to delineate the multiple aspects of the BWISM model.

The Berlin-White Integrated Science and Mathematics Model includes six aspects: (a) ways of learning, (b) ways of knowing, (c) content knowledge, (d) process and thinking skills, (e) attitudes and perceptions, and (f) teaching strategies.

- *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.
- *Ways of knowing.* Integrated school science and mathematics 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.
- *Content knowledge.* Science and mathematics can be integrated in terms of content that is overlapping or analogous. Big ideas or themes such as change, conservation, models, patterns, scale, symmetry, and systems can be found in both science and mathematics. The examination of concepts, principles, laws, and theories of science and mathematics reveal ideas that are unique to each discipline and ideas that overlap or are analogous (e.g., the fulcrum of a lever and the mean of a distribution).

- *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, hypothesizing, inferring, interpreting data, measuring, observing, predicting, and recognizing patterns are representative of this aspect.
- *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 education include accepting the changing nature of 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.
- *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 and problem solving, provide opportunities to use laboratory instruments and other tools, provide appropriate uses of technology (e.g., calculators and computers), encourage cooperative learning, embed assessment within instruction, and maximize opportunities for successful connections between science and mathematics.

Some of the aspects, namely, ways of learning, attitudes and perceptions, and teaching strategies, are not unique to integrated mathematics and science education. However, they often are found in the descriptions of integrated mathematics and science activities or integrated mathematics and science curriculum programs. These aspects may be perceived as necessary for effective integration, but in no way are they sufficient conditions. Ways of knowing, content knowledge, and process and thinking skills are the substantive and cogent aspects related to integrated mathematics and science teaching and learning.

The identification and elaboration of these aspects is meant to clarify the characteristics in constant interplay in defining integration. It is expected that the real value will be in identifying the links and overlap among the aspects rather than attending to them in isolation. The BWISM Model 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 mathematics and science teaching and learning. The Berlin-White Integrated Science and Mathematics Model is an interpretive or framework theory. The value of an interpretive or framework theory cannot be determined by testing, but rather is judged by communication and implementation. To assist in the use of the BWISM Model, a checklist-type template also has been developed to identify the relevant aspects of mathematics and science integration that are directly observable in an integrated mathematics and science lesson or activity.

Classroom Example: Natural Selection

As an example of an integrated mathematics and science activity, we have started with a commonly taught science lesson on natural selection. The science concepts and processes involved in this lesson include collecting and organizing data, diversity and adaptation, genetic variation, hypothesizing, interpreting data, measuring, modeling, observing, organisms and their environment, and prediction. The activity provides a natural and logical connection between the teaching and learning of mathematics and science. The mathematics concepts and skills involved in this activity include area measurement; graphing; non-standard and standard units of measurement; ratio and proportion; percentage; probability; randomization; and sampling, measurement, and experimenter error. Materials needed for this activity include three environments that are three sheets of 8 ½x 11 inch white paper, one with two black squares, one with a black circle, and one with a black irregular shape on it (see Figures 1 to 3); a supply of black-colored and white-colored hole punches; an 8 ½x 11 inch box with a lid (boxes from a copy store work well); graph paper; and a transparent centimeter grid. The following worksheets are used by students in a cooperative group setting to teach mathematics and science together (see Figures 4 to 6). After the students have completed the activity, each group shares their data from their Group Data Record sheet. Discussions related to ratios and proportions (e.g., white bugs to black bugs, white bugs to total bugs, black bugs to total bugs, white area to black area, white area to total area, and black area to total area) become meaningful in the context of this activity. Small group and whole class discussions can seamlessly flow between mathematics and science.

To characterize this integrated mathematics and science activity, we have used the BWISM template (see Figure 7). This template highlights the characteristics that are inherent in this activity with respect to five of the BWISM aspects: ways of knowing, content knowledge, process and thinking skills, attitudes and perceptions, and teaching strategies. The sixth BWISM aspect, ways of learning, is not included in the template as it is a rationale supportive of the other aspects. This exercise can be useful in planning instruction, selecting and developing activities, and the composite may serve as an operational definition to support and promote future empirical research.

References

American Association for the Advancement of Science. (1993). *Benchmarks for science literacy.* New York: Oxford University Press.

Berlin, D. F. (1991). *Integrating science and mathematics teaching and learning. A bibliography*. Columbus, OH: ERIC Clearinghouse for Science, Mathematics, and Environmental Education.

Berlin, D. F. (Ed.). (1994). *NSF/SSMA Wingspread Conference: A network for integrated science and mathematics teaching and learning. Conference plenary papers*. Bloomsburg, PA: School Science and Mathematics Association.

Berlin, D. F. (1999). *A bibliography of integrated science and mathematics teaching and learning: 1991-1999*. Unpublished manuscript, The Ohio State University, Columbus, OH.

Berlin, D. F., & White, A. L. (1992). Report from the NSF/SSMA Wingspread Conference: A network for integrated science and mathematics teaching and learning. *School Science and Mathematics, 92*, 340-342.

Berlin, D. F., & White. A. L. (1994). The Berlin-White Integrated Science and Mathematics Model. *School Science and Mathematics, 94*, 2-4.

Berlin, D. F., & White, A. L. (1995). Connecting school science and mathematics. In P. A. House & A. F. Coxford (Eds.), *Connecting mathematics across the curriculum. 1995 National Council of Teachers of Mathematics Yearbook* (pp. 22-33). Reston, VA: National Council of Teachers of Mathematics.

Berlin, D. F., & White, A. L. (1998). Integrated science and mathematics education: The evolution of a theoretical model and implications for instruction and assessment. In B. J. Fraser & K. Tobin (Eds.), *International handbook of science education* (pp. 499-512). Netherlands: Kluwer Publishers.

Brown, W. R., & Wall, C. R. (1976). A look at the integration of science and mathematics in the elementary school – 1976. *School Science and Mathematics, 76*, 551-562.

Education Development Center. (1970). *Final report of Cambridge Conference on School Mathematics, January 1962 – August 1970.* Cambridge, MA: Author. (ERIC Document Reproduction Service No. ED 188 904)

Huntley, M. A. (1998). Design and implementation of a framework for defining integrated mathematics and science education. *School Science and Mathematics, 98*, 320-327.

Lonning, R. A., & DeFranco, T. C. (1997). Integration of science and mathematics: A theoretical model. *School Science and Mathematics, 97*, 212-215.

National Council of Teachers of Mathematics. (1989). *Curriculum and evaluation standards for school mathematics.* Reston, VA: Author.

National Council of Teachers of Mathematics. (1998). Principles and standards for school mathematics: Discussion draft. Reston, VA: Author.

National Research Council. (1990). *Reshaping school mathematics: A philosophy and framework for curriculum*. Washington, DC: National Academy Press.

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

Roebuck, K. I., & Warden, M. A. (1998). Searching for the center of the mathematics-science continuum. *Science and Mathematics, 98*(6), 328-333.

Rutherford, F.J., & Ahlgren, A. (1990). *Science for all Americans.* New York: Oxford University Press.