What Does Integration of Science and Mathematics Really Mean?

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In this era of curriculum reconstruction, considerable attention is being focused on curriculum integration. The integration of science and mathematics continues to be interpreted in different ways. In this article, five different meanings of integration of science and mathematics-discipline specific, content specific, process, methodological and thematic-are investigated along with insturctional implications of these different approaches to integration.

Why Should Science and Mathematics Be Integrated?

Plans to change schools fundamentally require that we face many harsh realities. First, schools resist change with a remarkable resiliency. Efforts to restructure mathematics and science curricula historically seem to have had little effect on conventional uses of the textbook and methods of delivery. Second, all students, especially many low-income and minority students, need continuity between schooling and the rest of their lives. The inclusion of science in a mathematics curriculum, and vice versa, is one way to provide this continuity. The key thought behind this process is to develop relevancy and applicability of the discipline to the existing student experiences. Students must see mathematics, as well as science, as relevant components of their world. In other words, mathematics should no longer be seen as a discipline studied and applied for mathematics sake, but rather, because it will help make sense out of some part of our world. The "doing" of mathematics and the "doing" of science creates a new way for students to look at the world-a way that develops depth rather than breadth in a mathematics curriculum.

What Does Integration Mean?

The expression "integration of science and mathematics" is used in different ways throughout the science and mathematics education community. Because integration has been a commitment of the School Science and Mathematics Association, teachers need to understand different ways in which the term integration can be used and how they apply to the teaching of science and mathematics (Underhill, 1994). School Science and Mathematics has taken the lead in presenting teachers with models for integrating mathematics and science (Berlin, 1991; Berlin&White, 1994). Two questions seem to emerge from this discussion:

- To what extent can these integration efforts represent a bona fide integration of science and mathematics?
- To what extent has the integration of science and mathematics been merely cosmetic?

Answers to questions such as these are critical in this climate of significant curriculum reform. We became interested in exploring such questions as we sought to redesign preservice teacher education courses to integrate science and mathematics.

The Curriculum and Evaluation Standards for School Mathematics (National Council of Teachers of Mathematics [NCTM], 1989) are radically changing views of school mathematics, and Project 2061: Science for all Americans (AAAS, 1989) and subsequent benchmarks present blueprints for changing science education. Few educators would argue about the need for an interwoven, cross-disciplinary curriculum, but to many, the nature of the integration in many interdisciplinary projects is not readily apparent. A mom pervasive problem is that integration means different things to different educators. The purpose of this article is to describe the method, type, and value of integration between and among the two disciplines and to discuss the meaning of such integration.

Many topics in mathematics and science are touched upon at surface level, but few topics, historically, are covered or developed in much depth. Content coverage, rather than the provision of contextual understanding has been the valued mode in mathematics and science teaching. For these reasons, science and mathematics can be integrated to make disciplines relevant and meaningful to learner. Mathematics, when integrated with science, provides the opportunity for students to apply the discipline to real situations, situations that are relevant to the student's world and presented from the student's own perspective.

Integration deals with the extent to which teachers use examples, data, and information from a variety of disciplines and cultures to illustrate the key concepts, principles, generalizations, and theories in their subject area or discipline (Banks, 1993). Understanding different types of integration becomes necessary in order to begin to understand the integration found between and among science and mathematics. Five types of science and mathematics integration (discipline specific, content, process methodological, and thematic) can be used in interdisciplinary curriculum development (Miller, Davison, & Metheny, 1993).

Discipline Specific Integration

This approach to integration involves an activity that includes two or more different branches of mathematics or science. For example, discipline specific integration might include activities involving algebra and geometry in mathematics and activities infusing biology, chemistry, and physics in science. The project on *Scope, Sequence, and Coordination of Secondary* School Science (SS&C), initiated by the National Science Teachers' Association (NSTA), is a major reform of science at the secondary level. SS&C recommends that all students study science every year for six years and advocates carefully sequenced, well-coonlinated instruction of all the sciences. As opposed to the traditional "layer cake" curriculum in which science is taught in year-long discrete and compressed disciplines, the NSTA project provides for spacing-the study of each of the sciences spread out over several years (NSTA, nd). Also, in mathematics, systemic efforts in a number of states integrate the various branches of mathematics.

Examples from the traditional mathematics curriculum that integrate various branches of mathematics involvethestudy oftriangles. Consider the Pythagorean relation: The result is typically studied in a course in geometry, and a common proof uses similar triangles, while other readily accessible proofs use algebra. Likewise, proofs of compound angle formulas in trigonometry use analytical geometry.

In the science content areas, an example of a discipline specific integration activity might involve the study of an environmental issue. Models and strategies for teaching controversial and relevant environmental issues affecting all the sciences target discipline specific integration. Effective strategies for dealing with controversial issues within the science disciplines should consist of (a) the selection of an appropriate and relevant problem which is of local, regional, and national concern, (b) a problem that is multifaceted and influenced by scientific, environmental, and socioeconomic impacts on a decision, (c) the integration of geological, environmental, ecological, biological, and chemical databases specific to the issue, (d) strategies to structure the problem so that it is solved by the students, and (e) a problem that does not have one right answer. 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. An example for discipline specific integration might consist of one similar to the proposal of a high altitude hard rock mining site located in Montana in proximity to established wilderness areas and Yellowstone National Park. Students are required to gather their own data as well as data presented in preliminary environmental impact statements. Geological, environmental, biological, chemical, and socioeconomic databases affecting the problem are collected and used as the basis for making an informed decision regarding the impact of this mine.

Students learn that branches of mathematics as well as the branches of science are interrelated. The connections between sciences or fields of mathematics are preeminent. However, there are times when the branches of mathematics or science must be taught separately so that the students know the basic concepts, skills, and procedures.

Content Specific Integration

Content specific integration involves choosing an existing curriculum objective from mathematics and one from science. An activity is planned which will involve instruction in each of these objectives. It is content specific because it conforms to the previously developed curriculum, infusing the objectives from each discipline. In this type of integration, the challenge to the teacher is to weave together the existing programs in science and mathematics with objectives from two separate and distinct curricular For example, suppose that the content objective for mathematics is measurement and the science content objective is the study of dinosaurs. Then, using masking tape on the gym floor, they create life-size dinosaurs.

Another example is the study of simple machines in science and proportions in mathematics. Groups of students are given meter sticks, a fulcrum, and various metric weights. After balancing the lever, the students are asked to determine the relationship between the masses of the weights and their distances from the fulcrum. In mathematics, the students are working with proportions; in science, they are identifying the relationshipbetween work and a simple machine called a lever. After the students have worked on the relationship, the teacher can help the students arrive at the formula for a lever and its proportional relationship. The teacher might choose to give students the formula $m_1 * d_1 = m_2 * d_2$ and let them check the formula for their set of weights. Alternatively, the teacher can help the students derive the formula from the data they have collected.

The students explore the connections between mathematics and science and begin to see the relevancy of mathematics in the reality of science and vice versa. Note, not all mathematic and scientific concepts can be integrated. Basic mathematical and scientific concepts and processes may need to be taught first, and sometimes separately. Also, specific integration activities may involve only surface level organization and development. For example, in a mathematics class, counting paramecia under a microscope generally does not constitute valid integration of science.

Process Integration

Another approach to integrating curriculum in mathematics and science is through the use of real-life activities in the classroom. By conducting experiments, collecting data, analyzing the data, and reporting results, students experience the processes of science and perform the needed mathematics. A comparison of science processes with the mathematics dards in Table 1 iilustrates this idea.

The students practice formulating their own questions and finding the answers. These questions have meaning to the students and are ones they have some interest in answering. In small groups, they identify a problem, decide how to collect data, collect it, and then interpret these data. In doing this, the students count, measure, and compute. In addition, the students communicate the data orally and graphically. What is important is that mathematical operations are performed for a purpose: to answer questions that are of concern to the students about the problem under investigation and, generally about the real world.

For example, AIMS activities for Grades 5-9, *Math + Science: A Solution* (1987), contains many appropriate illustrations. In the M&M's (TM) activity, What's in the bag?" (p. 2 1), the science processes of identifying and controlling variables, hypothesizing, interpreting, and predicting are integrated with the mathematical skills of averaging, graphing, and estimating. General standards such as problem solving, communication, and reasoning are observed to represent both disciplines. A more student-centered approach to the M&M's activity involves having each group of students formulate a hypothesis about the M&M's in their bag. One group might conjecture that there will be more than 53 M&M's in the bag. Another group might claim that there will be more browns than any other color, and yet another group may believe that there will be fewer greens than any other color. The studentstesttheirownhypothesisand prepare a chart to demonstrate to the rest of the class. At the same time, theycheckthehypotheses oftheother group. Each group reports the result or testing Us own hypothesis and coordinates the findings of the other groups with their hypothesis; a judgment about the truth or falsity of the hypothesis is then based on majority findings from the class. By being involved in decision making in this manner, the students are practicing the processes of science and mathematics.

Table 1. ***Process Integration.***

Scientific Processes	Mathematics Standards
Observing	Problem Solving
communicating	Communication
using space relationships	Reasoning
Using time relationships	[illegible]
Classifying	Estimation
Using numbers	Number sense and numeration
Measuring	Whole number operations
[illegible]	Whole number computation
Inferring	Geometry and spatial sense
Controlling variables	Measurement
Interpreting data	Statistics and probability
Testing hypothesis	Fractions and decimals
Defining operationally	Patterns and relationships
Experimenting	
Imagining and creating	

Methodological Integration

The integration of methodology is rarely mentioned in current literature. In effect, "good" science methodology is integrated in "good" mathematics teaching. For example, mathematics developed under constructivist theory using science discovery and inquiry teaching techniques and building on prior knowledge characterizes another form of integration. The Standards of the NCTM state that students should be able to "apply mathematical thinking and modeling to solve problems that arise in other disciplines" (NCTM, 1989, p. 84).

But, the reverse might also be true. Should we strive to integrate mathematics with other disciplines or other disciplines with mathematics? If we choose the latter, the integration of science with mathematics, for example, it can be accomplished using science methods as the medium of integration Theuseofwhat is commonly known as the learning cycle (Karplus, 1967) as a method of teaching science can be directly infused with the development of teaching and learning models in mathematics. The learning cycle, as a teaching strategy, includes three main components: exploration, conceptual invention, and expansion of the idea. Historically, the most common learning model used in schools has been stimulus-response (S-R) where the student is rewarded for providing correct responses. This model assumes that the learner will respond if the stimulus is adequate. In contrast, the learning cycle provides the learner the opportunity to build upon previous knowledge, leads the learner to respond to those experiences, and develops new experiential structures applied to relevant situations (Renner & Marek, 1988). In the learning cycle format, the children work through an exploration using manipulatives and familiar activities to develop the concepts before symbols, procedures, and algorithms are taught. The teacher discusses the material to develop the conceptual understanding necessary, and eventually asks that the students apply what they have learned.

The methodological approach to the integration of scientific methods clearly focuses on "experimental science." At present, a focus on integration of methodologies means that students will investigate issues in both science and mathematics using related strategies such as inquiry, discovery, and the learning cycle.

Thematic Integration

The thematic approach begins with a theme which then becomes the medium with which all the disciplines interact. McDonald and Czemiak (1994) describe how the theme "Sharks" can be used to design an integrated curriculum unit In another example, the theme could be oil spills: in mathematics you would be working withvolume, surface area, and cost of cleanup; in science, you would be working with density and environmental aspects of oil spills. However, the thematic unit goes beyond integration of mathematics and science by including all other disciplines typically found in elementary and middle schools. For example, this unit would include an investigation of the economic and social implications of oil spills. In thematic integration, while science and mathematics integration is important, integration of individual disciplines is subsumed under the integration implied by the investigation of the thematic topic.

Conclusion

What does it really mean to integrate science and mathematics? Whether the integration of science and mathematics occurs within the disciplines or is infused with the disciplines, integration will provide for a more reality-based learning experience. As national, state, and local curriculum efforts continue, closer links between science and mathematics will be explored, and thereby lead to more obviously integrated science and mathematics curricula.

We have presented five different meanings of integrationinthisarticle. Eachoftheseintetpretations provides a valid approach to integrating the disciplines. We believe that the most potent approach to integration is to focus, not on science and mathematics content, but on scientific processes. We have used this strategy as a guide in the redesign of a methods course in science and mathematics. In an atmosphere of curriculum restructuring which focuses on connections between the disciplines, the use of scientific processes as an emphasis is deemed appropriate Such integration between science and mathematics can serve as a model for process integration across the curriculum. Theteachereducationcommunityneedsto more actively explore ways in which programs can be redesigned to respond to this change.

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Reprinted from *News Bulletin,* Nov., 1994, Dec. 1994, and Jan., 1995.