

Online Resource 5

25 Years Later: A Systematic Review of Mathematics and Science Integration in Primary and Secondary Education

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Online Resource 5. The 48 distinct definitions of MSI found in the corpus

Term used to refer to MSI	Authors	Definition
Integration	Huntley, 1998	An integrated curriculum is one in which a teacher, or teachers, explicitly assimilates concepts from more than one discipline during instruction. It is typified by approximately equal attention to two (or more) disciplines.
Integration	Lederman and Niess, 1998	On the other hand, many individuals define integration in a manner that maintains traditional disciplinary boundaries, and the focus of instruction stresses the interactions between mathematics and science. This second situation can also be labelled as interdisciplinary.
Integration	Lederman and Niess, 1998	A perusal of the eight manuscripts included in this special issue will clearly indicate that the inconsistent use of language reported in our February 1997 editorial continues to exist. In particular, several authors (e.g., Dickinson & Young; Matthews; Woodbury) use the definitions of integrated, interdisciplinary, and thematic stressed in our editorial, while other authors (e.g., Huntley; Lonning, et al.; Roebuck & Warden; Venville, et al.) tend to view integration as an umbrella term under which other categorizations can be placed. McComas & Wang have chosen to introduce a ""new"" term, blended, into the conversation.
Integration	Lederman and Niess, 1998	In particular, some individuals define integration as situations in which traditional disciplinary boundaries (e.g., mathematics and science) are significantly blurred or even lost.
Integration	Hopkins, 1937, cited by Czerniak et al., 1999	Historical references to integration (Hopkins, 1937, as cited in Beane, 1996) defined integration similarly as cooperatively planned, problem-centred, and integrated knowledge.
Integration	Berlin & White (Wingspread Conference) et al., 1992, cited by Czerniak et al., 1999	Berlin and White (1992) reported that in 1991, a group of 60 scientists, mathematicians, science and mathematics educators, teachers, curriculum developers, educational technologists and psychologists assembled at a conference funded by the National Science Foundation (NSF). These authors reported that, after three days of deliberation, the conference participants could not reach a consensus on the definition of integration of science and mathematics. However, one group proposed a working definition, ""Integration infuses mathematical methods in science and scientific methods into mathematics such that it becomes indistinguishable as to whether it is mathematics or science"" (p. 341). Berlin and White (1992) reported, however, that other conference participants feared that the merging of the disciplines might cause people to lose important philosophical, methodological, and historical differences between the two subjects.

Integration	Lederman and Niess, 1997, cited by Czerniak et al., 1999	Lederman and Niess (1997) defined integrated as a blending of science and mathematics such that the separate parts are not discernible. They used the metaphor of tomato soup: The tomatoes cannot be distinguished from the water or other ingredients.
Integration	Beane, 1995, 1996, cited by Czerniak et al., 1999	Beane (1995) suggested that curriculum integration begins with ""problems, issues and concerns posed by life itself (p. 616). He stressed that an integrated curriculum must have social meaning. Beane (1996) defined integration with four characteristics: (a) curriculum that is organized around problems and issues that are of personal and social significance in the real world, (b) use of pertinent knowledge in the context of topic without regard for subject lines, (c) knowledge that is used to study a current problem rather than for a test or grade level outcome, and (d) emphasis placed on projects and activities with real application of knowledge and problem solving.
Integration	Bloomfield, 2000	Instilling in students such understanding requires curricula that emphasize integrated science—the coordinated and synthesized presentation of concepts from the biological, physical, and mathematical sciences
Integration	Pang and Good, 2000	Note that the term integration is used as an overarching term under which any previous research connecting mathematics and science can be discussed.
Integration	Tyler, 1949, cited by Schwalbach and Dosemagen, 2000	On the other hand, the horizontal aspects of a curriculum focus on the relationships between algebra and physics and English. When these elements are successfully tied together, students have the opportunity to develop a global perspective and see the value of content in each area. Tyler (1949) referred to this horizontal relationship as ""integration"" (p. 85) and saw it as a way to unify students' ""outlooks, skills, attitudes and the like"" (p. 86).
Integration	Fogarty, 1991 Hayes Jacobs, 1989, cited by Schwalbach and Dosemagen, 2000	More recently, Fogarty (1991) and Hayes Jacobs (1989) supported integration of subject matter to show the connectedness of ideas, which deepens students' understanding of concepts within a discipline. They each delineated various degrees of curricular integration from a structure in which subjects are taught as distinctly different disciplines to a format that so thoroughly combines content from different subject areas that disciplines are indistinguishable.
Integration	Boris, 1976, cited by Hurley, 2001	Curriculum in which subject areas are correlated and taught as one instructional unit, or one subject area is used to enhance learning skills in another and related learning activities have been organized into instructional units which transcend subject lines. (Boris, 1976, p. 10)
Integration	McCliman, 1995, cited by Hurley, 2001	...blending of instructional concepts and data across two or more academic disciplines, accomplished in one course by one teacher or through efforts of two or more instructors from different disciplines relating their instruction to other academic disciplines. (McCliman, 1995, p. 8)"

Integration	Frykholm and Glasson, 2005	Similarly, common definitions of “integrated” teaching imply that science and mathematics can be blended seamlessly so that it is difficult to tell where the mathematics stops and the science begins.
Integration	Vasquez-Mireles and West, 2007	Integration of science and math usually means using math to teach science.
Integration	Vasquez-Mireles, 2009	Typically, the term integrate is used to denote the linking of math and science. Traditionally, this refers to math using science applications (usually in the form of word problems) and science using math as a tool. Technology has often connected the two disciplines.
Integration	Meyer et al., 2010	We want to highlight these as integration because they require someone to intentionally or knowingly make connections
Integration	Foutz et al., 2011	Here, integration of the math and science curricula is defined as creating a continuum of knowledge by building course content horizontally across classrooms within a grade and vertically between grades
Integration	Schleigh et al., 2011	In this paper we pose a new definition for curriculum integration which we argue is more usable by educators: Recognizing the strengths, weaknesses, commonalities, and distinctiveness among two or more fields of study, an integrated curriculum uses each field in the experiential learning of the other(s). Integrated curriculum is designed to allow students to simultaneously experience these fields of study in such a manner that students both do and learn important content and concepts in each of the respective subjects and glean further understanding from the gestalt formed among the subject matters. To make this definition more specifically directed to the integration of mathematics and science, we offer the following working example of the preceding definition: In respect to mathematics and science, integration is not simply recognition that mathematics and science are complementary or that mathematics is a tool for science and science is a context for mathematics. Integrated mathematics and science should not always begin with a scientific investigation which is then solved mathematically. Truly integrated instruction may begin with a problem scenario posed in either subject, pass through either subject in investigatory phases, and find a resolution in either subject all the while ensuring that neither subject is subservient to the other and that the level of content and conceptual coverage in both areas is at least commensurate with that which would be covered in standalone subject matter courses. Differentiating both this generic definition of integrated curriculum and the mathematics- and science centric concretization of such from the NSF’s definition is an issue of distinguishability. While the NSF’s definition for curricular integration denotes that the subjects in question become so thoroughly integrated that one becomes indistinguishable from

		the other, the definition and example provided in this discussion embraces the fact that any two subject areas have sufficient distinctiveness such that one subject can accentuate the interaction with, and learning of, the other subject. Altogether, denoting the two subjects as A and B, this can lead to the following variations in the problem posing-problem solving-solution sequence of the process: AAA, AAB, ABA, ABB, BAA, BAB, BBA and BBB"
Integration	Dressel, 1958, cited by Schleigh et al., 2011	In an argument for an integrated curriculum to improve education, Dressel (1958) defined integrative curriculum as planned learning experiences which provide learners with solid instruction in one field while developing their understanding of new relationships through other topical structures.
Integration	Davison, Miller, and Metheny, 1995, cited by Fox and Glen, 2012	The unit described here showcases “content specific integration” of science and mathematics in that the lessons meet content objectives from both science and mathematics (Davison, Miller, and Metheny 1995).
Integration	Cormas, 2017	Integration is generally associated with concepts which are brought together from more than one discipline or a concept from one subject which is applied to the practice of another.
Integration	Berlin and White, 1994 Breiner et al., 2012, cited by Aguirre- Muñoz et al., 2021	We refer to integration as instruction that coordinates the teaching of science and mathematics through engagement with disciplinary practices and/or coordinating concepts. Berlin and White (1994) emphasize big ideas common to both science and mathematics education to enhance integration. Breiner et al. (2012) emphasize disciplinary practices defined through the lens of CCSS-M and NGSS.
Integration	Miller et al., 1997, cited by McHugh et al., 2021	Miller et al. (1997) identified content-specific integration as choosing existing learning objectives from mathematics and science and combining the two objectives, such as using mathematical graphing skills during an ecology unit in science.
Integration	Lonning and DeFranco, 1997, cited by McHugh et al., 2021	Lonning and DeFranco (1997) described true mathematics-science integration as an equal balance between the subjects in a consistently unified curriculum.
Interdisciplinary	Lederman and Niess, 1998	On the other hand, many individuals define integration in a manner that maintains traditional disciplinary boundaries, and the focus of instruction stresses the interactions between mathematics and science. This second situation can also be labelled as interdisciplinary.

Interdisciplinary	Huntley, 1998	An interdisciplinary curriculum is one in which the focus of instruction is on one discipline, and one or more other disciplines are used to support or facilitate content in the first domain (for instance, by establishing relevance or context). In this case, connections between the disciplines are made only implicitly by the teacher(s). An interdisciplinary curriculum has the focus of instruction on one discipline, and other discipline(s) support or facilitate content in the first domain. The teacher(s) makes connections between the disciplines only implicitly.
Interdisciplinary	Jacobs, 1989, cited by Czerniak et al., 1999	Similarly, Jacobs (1989) defined interdisciplinary as "a knowledge view and curriculum approach that consciously applies methodology and language from more than one discipline to examine a central theme, issue, problem, topic, or experience."
Interdisciplinary	Lederman and Niess, 1997, cited by Czerniak et al., 1999	They defined interdisciplinary as a mixture of science and mathematics, in which connections are made between the subjects, but the two subjects remain recognizable. The metaphor is chicken noodle soup, where you can still recognize the broth, chicken, and noodles.
Interdisciplinary	Schwalbach and Dosemagen, 2000	Between the compartmentalized and integrated extremes are a variety of approaches, which will be referred to here as interdisciplinary.
Interdisciplinary	Frykholm and Glasson, 2005	To summarize briefly, definitions of interdisciplinary teaching include the assumption that the integrity of disciplinary boundaries will be preserved through exploration of common contexts that promote learning of both science and mathematics. Such a view predicates that teachers have both the content knowledge and pedagogical content knowledge to teach two disciplines successfully, science and mathematics.
Interdisciplinary	Stember, 1991, cited by Weinberg and McMeeking, 2017	This definition implies integration and synthesis of the knowledge and approaches from different disciplines in order to address a problem or issue (Stember, 1991).
Interdisciplinary	Repko, 2008, cited by Weinberg and McMeeking, 2017	As Repko (2008) notes, interdisciplinary can be viewed as "between two or more fields of study."
Interdisciplinary	Merriam-Webster's, 2011, cited by Weinberg and McMeeking, 2017	Finally, interdisciplinary implies a connection such as "between, among, in the midst, and reciprocal" (Merriam-Webster's, 2011).

Interdisciplinary	Holubova, 2018	Interdisciplinary study is an important teaching strategy that enables learners making connections across science disciplines and applies the knowledge in real life situations
Interdisciplinary	Shang, 2021	Interdisciplinary refers to the generation of new concepts and theories by integrating concepts, methods, and theoretical frameworks of different disciplines, so as to generate new insights and understandings of problems encountered in scientific research.
Thematic	Lederman and Niess, 1997, cited by Czerniak et al., 1999	Finally, Lederman and Niess (1997) defined thematic as a unifying topic or subject transcending traditional subject boundaries.
Connection	Frykholm and Glasson, 2005	In what may be a more realistic and hopeful approach, therefore, we advocate the use of terminology that includes the notion of connections between science and mathematics – connections that are situated authentically in the respective practices of each field and in the common experiences of learners. Although teachers may not have enough knowledge to “integrate” instruction, or are not able (i.e., lack of time, school structure, etc.) to work collaboratively toward “interdisciplinary” teaching, many teachers are able to recognize and build upon various connections between mathematics and science that they see as intuitive and relevant.
Correlation	West and Tooke, 2001, cited by Vasquez-Mireles and West, 2007	We are calling the connections between science and math correlations as proposed by West and Tooke (2001) who suggest that teaching certain concepts in one discipline can enhance the understanding of specific concepts in the other discipline. However, the notion of correlation expands integration to create a lesson in which concepts from both disciplines are almost equally taught. However, a correlated math-science lesson also • has the pertinent math and science objectives aligned with state standards; and, • teaches parallel science and math ideas equally.
Transdisciplinary	Steiner, 1998 Balsiger, 2004 Singer & Gregg, 2004 Pohl, 2005, cited by Paige et al., 2008	In an educational setting, a transdisciplinary approach tackles the complexity of science, challenges knowledge fragmentation as well as real research problems. It brings a complexity to classroom practice when there is also the need to develop conceptual understanding, skills in the synthesis of ideas from a number of discipline areas, and dispositions to want to take social and environmental action. Steiner’s definition of transdisciplinary as “interdisciplinary + participation” is also useful (Steiner cited in Jucker, 2002, p. 15). The narrow vision of discipline-based experts do not address fundamental issues but only topics isolated from their societal contexts. Much of science and mathematics that is taught today in schools is the antithesis of a transdisciplinary approach and more in line with the narrow topic centred approach within particular disciplines. Transdisciplinarity is issues based. Balsiger (2004) states that transdisciplinarity is a scientific approach to understanding the world with a strong

		orientation towards societal problems. Transdisciplinary approaches deal with real world topics and generates knowledge that addresses societal problems but also contributes to their solutions (Balsiger, 2004). A key factor when using transdisciplinary approaches is that the solution also needs to be technically and economically feasible, socially acceptable and ecologically sustainable (Singer & Gregg, 2004, p. 8). (Pohl, 2005, p. 159) says that “One aim of transdisciplinary research is to get natural and social scientists to collaborate, so as to achieve an integrated view of a subject that goes beyond the viewpoints offered by any particular discipline”.
Infusion	Burghardt et al., 2015	MSTP introduced the term mathematics infusion as an approach to make mathematical interconnections. Similar to enhanced mathematics integration (Hurley, 2001), infusion is where mathematics is taught in a science or technology lesson at critical points leading to a natural fit within the predominant discipline.
Multidisciplinary	Kim and Cho, 2015	Multidisciplinary education compares a concept in one subject with a similar concept in another subject.
Interdisciplinary pedagogical content knowledge	An, 2017	In brief, interdisciplinary pedagogical content knowledge (IPCK) is the specific capacity for teachers to accomplish the following: (1) work with interdisciplinary considerations that include an understanding of the representation of concepts using themes across curriculum boundaries; (2) apply pedagogical methods and interdisciplinary themed activities in addressing content areas from multiple subjects simultaneously; (3) identify knowledge connections within and between particular subjects, and develop lessons based on such connections; and (4) employ knowledge of how interdisciplinary explorations can be developed as a part of an instructional process wherein students link existing knowledge across curricula, while presenting that new knowledge through contexts from multiple subjects.
Cross-disciplinary	Stember, 1991, cited by Weinberg and McMeeking, 2017	Stember (1991) describes cross-disciplinary as “the viewing of one discipline from the perspective of another” (p. 4).
Multidisciplinary	Merriam-Webster’s, 2011 Stember, 1991, cited by Weinberg and McMeeking, 2017	Multi brings in “more than one or two” in the definition (Merriam-Webster’s, 2011), and Stember distinguishes this from cross-disciplinary through a team approach where each team member offers the different perspective.

Synergy	Breiner et al. (2012) Berlin and White (1994), cited by Aguirre-Muñoz et al., 2021 We refer to integration as instruction that coordinates the teaching of science and mathematics through engagement with disciplinary practices and/or coordinating concepts. Breiner et al. (2012) emphasize disciplinary practices defined through the lens of CCSS-M and NGSS. Berlin and White (1994) emphasize big ideas common to both science and mathematics education to enhance integration. We integrate these two perspectives to call attention to the synergistic relationship of content and disciplinary practices of both disciplines. Synergistic relationships refer to content concepts that correspond conceptually in science and mathematics. Thus, their integration results in a better understanding of a phenomenon. Synergistic disciplinary practices refer to those practices that overlap in disciplinary norms, cognitive demand, or complex problem-solving.
Crosscutting	NRC et al., 2012, cited by McHugh et al., 2021 The Framework for K-12 Science Education incorporated the notion of integration in its definition of crosscutting concepts, which they defined as concepts that bridge disciplinary boundaries, having explanatory value... these concepts help provide students with an organizational framework for connecting knowledge from various disciplines into a coherent and scientifically based view of the world (NRC 2012, p. 83).