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ABSTRACT

During the past century, one distinctive effort to improve science and mathematics education is an approach that recognizes the commonalities between science and mathematics and seeks to appropriately and effectively integrate these two disciplines in teaching and learning. Philosophically and theoretically, there is strong support for the integration of science and mathematics education as a way to enrich science and mathematics learning experiences and improve student understanding of and attitude toward these disciplines. This bibliography was 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. The first volume of the bibliography contained 555 citations published between 1905 and the first half of 1991 related to the integration of science and mathematics teaching and learning. This volume is an updated bibliography of publications from the second half of 1991 through 2001 and includes documents that were inadvertently omitted in the first volume. The major purposes of both volumes are to: (1) provide resources for classroom practice, policy decisions, and research; (2) facilitate the development of new curriculum and instructional materials; (3) stimulate additional research; (4) identify K-12 and teacher preparation and enhancement models; and (5) present a century-long portrayal of trends and issues. (MVL)

School Science and Mathematics Association
Topics for Teachers Series Number 7

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INTEGRATING SCIENCE AND MATHEMATICS EDUCATION: HISTORICAL ANALYSIS

Introduction

During the past century, one distinctive effort to improve science and mathematics education is an approach that recognizes the commonalities between science and mathematics and seeks to appropriately and effectively integrate these two disciplines in teaching and learning (Berlin & White, 1998; Lee, 2000; Pang & Good, 2000). A number of national science and mathematics education professional associations, and recently technology education associations, are united in their support for the integration of science and mathematics teaching and learning. The national education reform documents published by the following associations recommend the integration of 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 (1989, 1990, 1996); National Science Teachers Association (1992, 1997).

The following excerpts from national educational reform documents attest to the significance and timeliness of this compilation of the literature related to integrated science and mathematics teaching and learning. These documents address the interrelated nature of science and mathematics along with implications for curricula and instructional practice.

Benchmarks for Science Literacy (American Association for the Advancement of Science, 1993) while recognizing the uniqueness of each discipline, suggests a symbiotic relationship between science, mathematics, and technology.

> 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. (p. 3)

A similar position is reflected in the Connections Standard promoted by the mathematics education community. Opportunities for students to recognize and apply mathematics in contexts outside of mathematics are central to this process standard.

> 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. (p. 65)

The current national science and mathematics standards that guide both state curriculum frameworks and local courses of study affirm the importance of the integration of science and mathematics education.

> 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)
>
> 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. (National Council of Teachers of Mathematics, 2000, p. 66)

Philosophically and theoretically there is strong support for the integration of science and mathematics education as a way to enrich science and mathematics learning experiences and improve student understanding of and attitude toward these disciplines. 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.

Purpose

As identified in the first volume of the bibliography (Berlin, 1991), there were 555 citations published between 1905 and the first half of 1991 that relate to the integration of science and mathematics teaching and learning. This is an updated bibliography (Volume 2) of publications from the second half of 1991 through 2001, including documents that were inadvertently omitted in the first volume of the bibliography.

The major purposes of both the first and second volumes of the bibliography of integrated science and mathematics teaching and learning literature are to:

1. provide resources for classroom practice, policy decisions, and research;
2. facilitate the development of new curriculum and instructional materials;
3. stimulate additional research;
4. identify K-12 and teacher preparation and enhancement models; and
5. present a century-long portrayal of trends and issues.

Method

As a first step to compile the bibliography, relevant journals were identified using the Current Index to Journals in Education (CIJE) provided by the Educational Resources Information Center (ERIC). ERIC indexes more than 1,100 journals, including science and mathematics education journals published throughout the world. Science, mathematics, and technology education journals covered by CIJE and ERIC Documents (see Appendix for a listing of relevant journals) were examined. As a second step, after all articles related to the integration of science and mathematics education were selected,

a content analysis was used to determine the major theme and content of each article. The authors read all selected articles repeatedly and used a process of dialogue and consensus to ultimately place each article in one of the five sections of the bibliography. As a final step, all articles were subjected to another review with regard to section classification.

For consistency, this second volume of the bibliography of integrated science and mathematics teaching and learning literature used the same process of analysis and delineation of sections as employed in the first volume by Berlin (1991). This second bibliography of integrated science and mathematics teaching and learning literature has been divided into five sections: (1) Curriculum [C], (2) Instruction [I], (3) Research [R], (4) Curriculum-Instruction [C-I], and (5) Curriculum-Evaluation [C-E]. It should be noted that articles in each of the five sections with their publication year followed by a lower case letter refer to citations by the same author with the same publication date appearing in the alphabetic listing of the bibliography.

A narrow definition of curriculum has been used. Curriculum relates to intended learning or the outcomes of being educated. Citations in the Curriculum Section primarily deal with the content in a course or group of courses or simply put "what students are taught". Instruction is the process of implementing the curriculum. It refers to the structuring of the learning environment to coordinate elements of time, space, materials, equipment, and personnel. Simply put, citations in the Instruction Section primarily relate to "how students are taught". While it is recognized that the instruction literature must initially deal with the curriculum, those documents that have been placed in this category primarily deal with the instructional elements. The Research Section includes both theoretical and empirical research documents. The theoretical research documents are comprised of theoretical models and frameworks related to the integration of science and mathematics teaching and learning. Empirical research includes research documents that are data based and generate new knowledge and understandings from both qualitative and quantitative inquiry. Empirical research also includes reviews of research. Two sections were used in order to classify curriculum programs that include instructional activities (Curriculum-Instruction Section) and evaluation of curriculum programs (Curriculum-Evaluation Section). It should be noted that while most of the citations can be distinctly placed in one of the bibliography sections, there are some that cannot and placement decisions were based upon the primary focus of the document.

Analysis and Discussion

The topic of integrated science and mathematics teaching and learning is not new. The earliest document referenced in the first bibliography of integrated science and mathematics teaching and learning literature was published in 1905 in *School Science and Mathematics*. At the turn of the 20th century, numerous articles appeared in this same journal published by the Central Association of Science and Mathematics Teachers (CASMT). In 1970, this association was renamed the School Science and Mathematics Association (SSMA) and their journal, *School Science and Mathematics*, continues to be a principal source for integrated science and mathematics articles. National funding agencies have also been involved in integration efforts.

A cursory look at both the first and second volumes of the bibliography of integrated science and mathematics teaching and learning literature reveals that there

continues to be a plethora of terms being used to refer to "integration"; e.g., connections, cooperation, coordinated, correlated, cross-disciplinary, fused, interactions, interdependent, interdisciplinary, interrelated, linked, multidisciplinary, transdisciplinary, and unified. These terms represent various degrees of integration including mathematics taught as a prerequisite tool for science, mathematics applied to science problems, science phenomena translated into mathematical terms, and science and mathematics taught in concert in a real-world, problem-solving context.

Overview of the Bibliography (Volume 2)

The second volume of the bibliography of integrated science and mathematics teaching and learning literature includes a total of 402 documents. A comparison of the separate sections of the bibliography indicates that the documents related to instruction permeate the literature. Specifically, there are 255 documents in the Instruction Section as compared to 40 in the Curriculum Section, 83 in the Research Section, 20 in the Curriculum-Instruction Section, and 4 in the Curriculum-Evaluation Section. Table 1 provides the totals for each of the five sections along with the number of articles by year, 1991 to 2001, for each section.

Table 1

Integrated Science and Mathematics Teaching and Learning Literature by Section and Year (Volume 2)

Year	Curriculum	Instruction	Research	Curriculum-Instruction	Curriculum-Evaluation	Total
1991	8	10	8	1	1	28
1992	5	14	8	2	0	29
1993	8	43	7	5	1	64
1994	8	46	7	4	1	66
1995	1	23	8	1	1	34
1996	2	21	1	3	0	27
1997	1	23	7	1	0	32
1998	2	20	16	0	0	38
1999	0	17	6	1	0	24
2000	3	25	7	1	0	36
2001	2	13	8	1	0	24
Total	40	255	83	20	4	402

Many of the documents in the Curriculum Section describe courses, projects, or programs designed to integrate science and mathematics at a variety of levels, K-16. In addition, teacher education integrated science and mathematics courses, projects, or programs for both pre-service and in-service teachers are cited in this section. The addition of teacher education programs designed to prepare teachers to integrate science and mathematics education is any interesting trend unique to the second bibliography.

As in the first bibliography, the greatest number of citations appears in the Instruction Section (n = 255). The science concepts and processes and mathematics concepts and skills that emerged in the analysis of the instructional documents in the first bibliography were also apparent in the second bibliography. 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 were most frequently cited in the instruction literature. The most frequent mathematics concepts/skills mentioned or implied include: angular measurement, estimation, formulas and equations, fractions, function, geometry, graphs, modeling, patterns, percentage, probability and statistics, problem solving, ratio and proportion, and variable. Analysis of this literature reveals that most of the documents are basically science instructional activities or lessons for middle and secondary school students that include mathematics-related concepts. During the years 1993 and 1994, there was a noticeable increase in the number of integrated science and mathematics instructional documents. Perhaps, the numerous meetings and preliminary documents related to the development of the national standards for science education along with implementation of the national standards for mathematics education encouraged individuals to explore instructional connections between these two disciplines.

Update of the Bibliography (Volume 1)

The first volume of the bibliography of integrated science and mathematics teaching and learning literature (Berlin, 1991) identifies 555 relevant documents published between 1905 and 1991, a period of 87 years. Thirteen subsequent citations were identified for this period of time resulting in a revised total of 568. Table 2 displays the integrated science and mathematics teaching and learning literature by section and by year as reported in the first bibliography (Berlin, 1991) plus omissions identified during the compilation of this second volume of the bibliography.

Table 2

Integrated Science and Mathematics Teaching and Learning Literature by Section and Year (Volume 1, Berlin, 1991) Plus Omissions (Volume 2, Berlin & Lee, 2003)

Year	Curriculum	Instruction	Research	Curriculum-Instruction	Curriculum-Evaluation	Total
1905	2					2
1926	1					1
1929	1					1
1930	1					1
1931	1					1
1935	1					1
1936	1					1
1937	1					1
1939	1					1
1941	1					1
1942		2				2
1943			1			1
1945	1					1
1950		1				1
1952	1					1
1957		2				2
1958	1					1
1959	1		1		1	3
1961	4	1				5
1962	3	1				4
1963	1	1	1	1		4
1964				1		1
1965	1					1
1966	3		1			4
1967			1	1		2
1968		1		2	1	4
1969	0 (+1)	1	1	2		4 (+1)
1970	2	2		3		7
1971	1	5	1	29		36
1972	4	5		5		14
1973	1	3	1	2		7
1974	2	3		2		7
1975	10	11		4	3	28
1976	1	3	2	15	2	23
1977		3	3	27	2	35
1978	2	3	1	3	1	10
1979	4	16				20
1980	2	6		5		13
1981	2	5	2	1 (+1)		10 (+1)
1982		6		1		7
1983	2	4 (+1)	2	2		10 (+1)
1984	1	3	7	2		13
1985	2	19	4 (+1)	6		31 (+1)
1986	4	11	3	12		30
1987	5	39	2 (+2)	24	1	71 (+2)
1988	4	19 (+1)	2 (+1)	5		30 (+2)
1989	3	42	3 (+1)	3		51 (+1)
1990	5	28 (+3)	1 (+1)	5		39 (+4)
1991		5	1	3	2	11
Total	84 (+1)	251 (+5)	41 (+6)	166 (+1)	13	555 (+13)

Comparison of the Bibliography (Volumes 1 and 2)

In 1992, the Department of Education funded the Eisenhower National Clearinghouse (ENC) to develop a database of all K-12 mathematics and science resources. A recent search of the ENC database resulted in the identification of 1,165 integrated science and mathematics curriculum-instruction resources. Consequently, the second bibliography does not include the vast number of integrated curriculum-instruction resources now available in the ENC database.

Table 3

Adjustment of the Integrated Science and Mathematics Teaching and Learning Literature for the Curriculum-Instruction Section by Year (Volume 1, Berlin, 1991)

Year	Curriculum-Instruction	Curriculum-Instruction Programs	Total
1905 - 1962			
1963	1	(-1)	0
1964	1		1
1965			
1966			
1967	1		1
1968	2		2
1969	2		2
1970	3		3
1971	29	(-28)	1
1972	5	(-1)	4
1973	2		2
1974	2	(-1)	1
1975	4		4
1976	15	(-11)	4
1977	27	(-27)	0
1978	3		3
1979			
1980	5	(-2)	3
1981	1 (+1)		1
1982	1		1
1983	2	(-2)	0
1984	2		2
1985	6	(-1)	5
1986	12	(-10)	2
1987	24	(-22)	2
1988	5	(-5)	0
1989	3	(-2)	1
1990	5	(-4)	1
1991	3	(-3)	0
Total	166 (+1)	(-120)	47

In order to compare the first bibliography to the second bibliography, it is necessary to modify the numbers reported in the Curriculum-Instruction Section of the first bibliography. The first bibliography includes a substantial number of curriculum-instructional programs (e.g., Activities Integrating Mathematics and Science and Great Explorations in Math and Science) designed as total programs or as supplements to the

established curricula. These programs and their corresponding documents/books were included in the first bibliography because, at the time, there was no other cataloging of these resources.

To make a valid comparison of the first to the second bibliography, the numbers in the first volume of the bibliography have been adjusted to subtract curriculum-instruction resources that are now catalogued by ENC (n = 120) and add the one citation that was previously omitted. (See Table 3.) The adjusted number of citations in the Curriculum-Instruction Section in the first volume of the bibliography is 47. Accordingly, the adjusted total number of citations in the first volume of the bibliography is 448.

Overall, a comparison between the first volume (1905-1991) and the second volume (1991-2001) of the bibliography reveals a dramatic increase in the number of documents related to the integration of science and mathematics teaching and learning. For the years 1905-1991 or for a period of 86.5 years, 448 citations (based on adjusted numbers for the Curriculum-Instruction Section) were identified. In contrast, for the years 1991-2001, a period of only 10.5 years, 402 citations were identified. This is a remarkable statistic, nearly the same number of articles were published in the last 10.5 years as in the preceding 86.5 years.

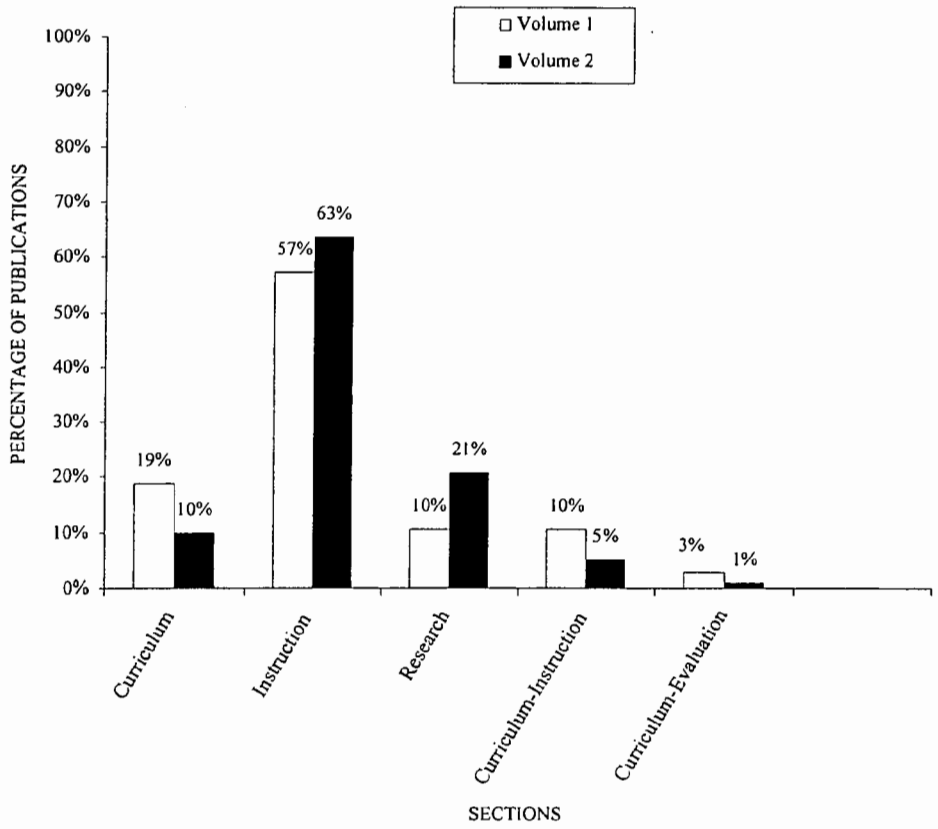

Figure 1. Percentage of publications in the bibliography (Volumes 1 and 2) by section.

Figure 1 illustrates the percentage of documents in each of the five sections in the first volume of the bibliography compared to the second volume of the bibliography. Comparing the Curriculum Section in the first and second volumes of the bibliography indicates that the percentage of articles devoted to curriculum is 19% and 10% respectively. However, as previously noted, the second volume of the bibliography includes many more documents related to teacher education programs for both pre-service and in-service teachers designed to integrate science and mathematics education.

What is rather startling is that the number of instructional documents in the first bibliography covering approximately 87 years is almost the same number as in the second bibliography covering approximately 11 years. However, the percentage of instructional documents in the first bibliography compared to the second bibliography has increased from 57% to 63%. Surprisingly, the largest number of instructional activities published in the last decade focused upon middle school science, secondary mathematics, and secondary science, in decreasing order. Approximately the same number, nearly three times lower than the aforementioned instructional activities, were developed for elementary school mathematics, elementary school science, and middle school mathematics. These grade level distinctions are in stark contrast to those found in the first volume of the bibliography where most of the instructional documents focused upon upper elementary and middle school grades. The attention to integrated instructional activities for secondary mathematics and secondary science classrooms is clearly a dramatic, unanticipated finding in the second volume of the bibliography.

The first volume of the bibliography revealed a profound lack of research documents. Out of the original 448 citations (adjusted number), only 10% relate to research over a period of 86.5 years. In contrast, the second volume of the bibliography of integrated science and mathematics teaching and learning literature identifies 21% of the citations related to research, double the percentage of articles devoted to research in a mere 10.5 years. It should be noted that there was nearly a balance between theoretical and empirical research and that there was considerable attention to the development of theoretical models for the integration of science and mathematics education during the last decade. Similar to the trend noted in the Curriculum Section, theoretical models and empirical research related to integrated science and mathematics courses, projects, and programs for pre-service and in-service teachers have emerged in the last decade. As noted in the first volume of the bibliography, the terminology and definition of integration is not at all consistent within the literature precluding reliable and valid comparisons among research studies. Clearly, there remains a critical need for careful conceptualization and additional research on integrated science and mathematics teaching and learning for all grade levels and teacher education preparation and enhancement programs.

The percentage of documents focused on curriculum-instruction has dropped from 10% (first volume) to 5% (second volume). Although there are many more current integrated curriculum-instruction resources, the percentage of articles describing both curriculum and instruction appears to be diminishing.

A similar diminishing pattern appears in the Curriculum-Evaluation Section comparison. The percentage of articles in this section reported in the first bibliography is 3% and the percentage of articles in the second bibliography is 1%.

The graphical display of all the documents related to the integration of science and mathematics teaching and learning that have been published each decade through 1999 and from 2000 to 2001 yields an impressive and revealing trend. Figure 2 depicts the data.

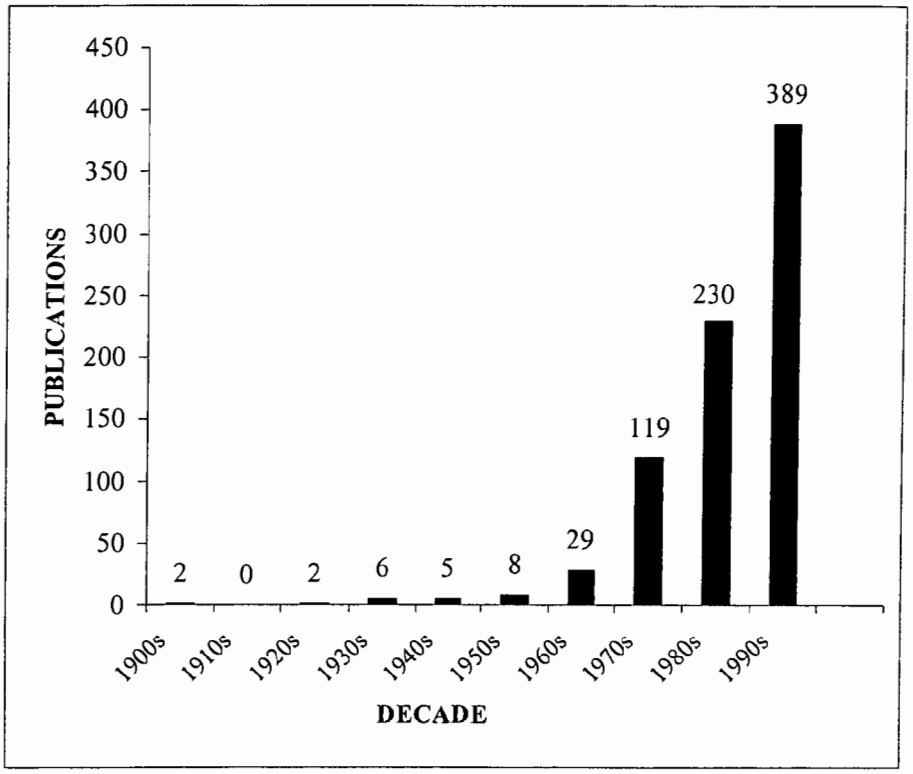

Figure 2. Integration of science and mathematics teaching and learning literature by decade.

The pattern of growth in the number of integrated science and mathematics documents since the 1970s seems to be continuing into the 21st century and may reflect increased federal funding, recommendations from national reform documents, and teacher education programs related to integrated science and mathematics education. Using a line of best fit determined by a regression analysis, approximately 575 documents related to the integration of science and mathematics education is projected for the next decade, 2000-2009. (See Figure 3.)

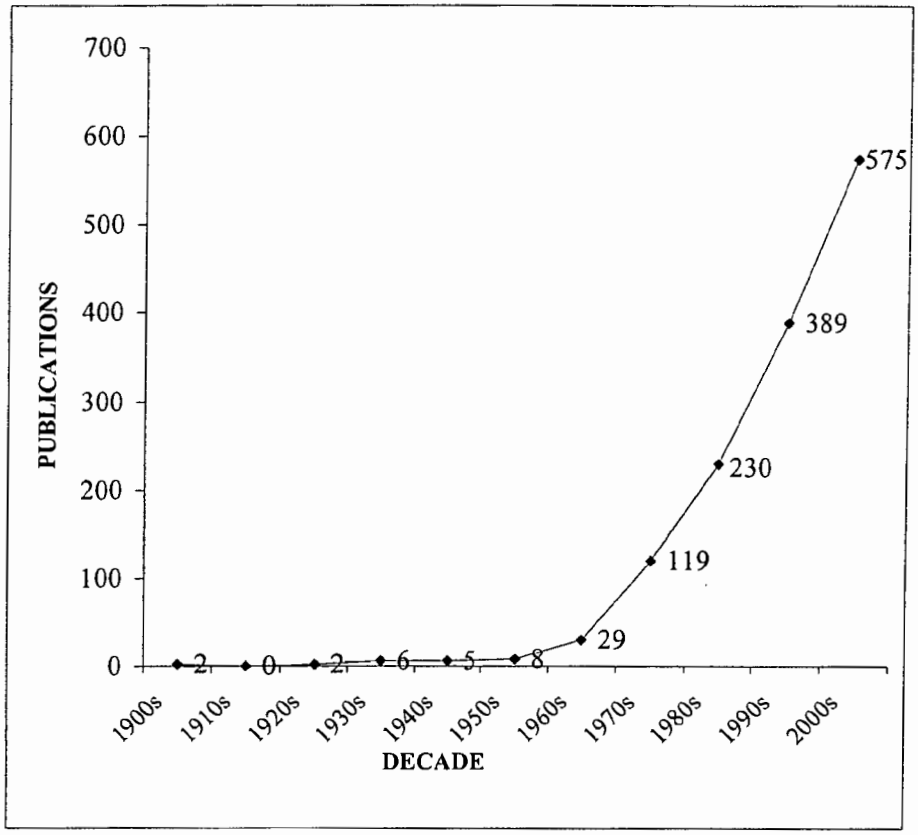

Figure 3. Projected integration of science and mathematics teaching and learning literature by decade.

It is hoped that this bibliography will generate additional dialogue, development, and research in order to gain a better understanding of integrated science and mathematics teaching and learning. These efforts can lead to enriched classroom experiences, promote student engagement in learning, and improve student attitude toward and achievement in both science and mathematics.

Finally, although there are 448 citations (adjusted number) in the first volume of the bibliography and 402 citations in the second volume of the bibliography, this listing is not intended to be exhaustive. The authors apologize to any author whose work in this area has been inadvertently omitted and communication as to any omissions would be appreciated. This bibliography is not intended as a final product, but will be periodically updated.

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APPENDIX

LISTING OF JOURNALS IN THE BIBLIOGRAPHY

American Journal of Education
American Journal of Physics
Australian Primary Mathematics Classroom
British Journal of Educational Technology
Community College Journal of Research and Practice
Curriculum Review
Education
Educational Leadership
Educational Technology
Educational Technology Research and Development
International Handbook of Science
International Journal of Mathematical Education in Science and Technology
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Learning
Mathematical Geology
Mathematics in School
Mathematics Teaching
Mathematics Teaching in the Middle School
Media and Methods
Micromath
Ohio Journal of School Mathematics
Primus
Research in Science Education
Review of Educational Research
School Science and Mathematics
School Science Review
Science
Science Activities
Science and Children
Science Education
Science Educator
Science Scope
Studies in Higher Education
Teaching Children Mathematics
TechTrends
The Arithmetic Teacher

The Journal of Technology Studies
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