Effects of integrative approaches among science, technology, engineering, and mathematics (STEM) subjects on students' learning: A preliminary meta-analysis

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Abstract

Within the literature there has been a call for the integration of science, technology, engineering, and mathematics (STEM) disciplines; however, little research has been conducted to investigate the effects of integrative approaches among STEM subjects. The purpose of this study was to synthesize the findings from existing research on the effects of integrative approaches among STEM subjects on students' learning. Meta-analysis was employed to address the research questions of this study. Twenty-eight studies were selected and thirty-three effect sizes were calculated to examine the effects of integrative approaches among STEM subjects. With respect to the grade levels, the effects of integrative approaches showed the largest effect size at the elementary school level and the smallest effect size at the college level. Regarding the types of integration, STEM, the integration of four subjects, presented the largest effect size, and E-M and M-S-T showed the smallest effect size. In addition, concerning the achievement through integrative approaches, STEM achievement showed the highest effect size and mathematics achievement showed the smallest effect size. The results of this preliminary meta-analysis reveal that integrative approaches among STEM subjects have positive effects on the students' learning. Further empirical research on the effects of STEM education needs to be conducted to confirm the findings of this preliminary meta-analysis.

Introduction

Science, technology, engineering, and mathematics (STEM) education is a crucial issue in current educational trends (Berlin & Lee, 2005; Kuenzi, 2008; Reiss & Holman, 2007; State Educational Technology Directors Association [SETDA], 2008). Research shows that integrative approaches improve students' interest and learning in STEM. STEM learning experiences prepare students for the global economy of the 21st century (Cachaper et al., 2008; Cullum et al., 2007; Hynes & Santos, 2007) and students need a solid STEM knowledge to become ready for college and employment. According to the U.S. Department of Education (2007), 75% of the fastest growing occupations require significant science or mathematics training. The importance and value of STEM education have resulted in the need for significant national reform in K–16 education and curriculum.

However, STEM disciplines and careers have not been attractive to American students, and the crisis in the STEM fields is nationally recognized (Apedoe et al., 2008; Basalyga, 2003; Cachaper et al., 2008; Lam et al., 2008). The American College Testing (ACT) study reported that the number of students who indicated engineering as a career goal dropped from 9% in 1997 to 6% in 2002 (Basalyga, 2003). The declining enrollment in STEM disciplines is expected to create a shortage of scientists and engineers in the U.S. workforce in the near future (Berrett, 2007; Business Roundtable, 2008; Ross & Bayles, 2007; SETDA, 2008). The U.S. Department of Education (2007) noted that one of the federal STEM education goals for K–12 education, in order to avoid the declining STEM pool of human resources in the U.S., is "to prepare all students with the science, technology, engineering, and math skills needed to succeed in the 21st-century technological economy, whether in postsecondary education or the workforce; and graduate students with the capability and motivation to become STEM professionals, educators, and leaders" (p. 18).

In recent years, STEM education has been facing a new challenge to investigate empirical evidence in order to support the effective implementation of STEM education (Froyd & Ohland, 2005; Kwon & Lee, 2008; Narum, 2008; U.S. Department of Education, 2007; Venville et al., 2000). Despite many efforts to disseminate and implement STEM education, little research has been documented to determine the effects of the integrative approaches among STEM subjects on the students' achievement (Hurley, 2001; Judson & Sawada, 2000; Pang & Good, 2000; Venville et al., 2000). Due to the lack of a comprehensive review regarding the effects of integrative approaches among STEM subjects on academic achievement, many teachers are unaware of the benefits of the integrative approaches for student learning. An examination of the effects of the integrative approaches among STEM subjects is a research topic that might guide and resolve some of the current challenges in STEM education.

This preliminary meta-analysis is intended to facilitate a greater understanding of the effects of integrative approaches among STEM subjects, and the findings will shed light on students' learning in STEM subjects. Included in this paper is a brief overview of some integrative efforts in STEM education. Research questions are four-fold: first, what is the effect of an integrative approach among STEM subjects?; second, how does the effect of integrative approaches among STEM subjects differ by grade levels?; third, what type of integrative approaches is more likely than others to lead to the improvement of students' achievement?; and fourth, what achievement score among STEM subjects is most improved through integrative approaches?

Integrative Efforts in STEM Education

Integrative approaches are defined as "approaches that explore teaching and learning between/among any two or more of the STEM subject areas, and/or between a STEM subject and one or more other school subjects" (Sanders, 2009, p. 21). STEM educators have made an effort to employ the integrative approaches with various methodologies (Apedoe et al., 2008; Cantrell et al., 2006; Childress, 1996; Elliott et al., 2001; Everett et al., 2000; Fortus et al., 2005; Judson & Sawada, 2000; Kolodner et al., 2003; Mehalik et al., 2008; Norton, 2007; Riskowsk et al., 2009; Roth, 2001; Sadler et al., 2000; Venville et al., 2000, 2004). Although research on the integrative approaches among STEM subjects has grown, there are still a number of practical challenges (Zubrowski, 2002). STEM teachers' implementation of the integrative approaches highly depends on their individual characteristics when accepting a new instructional method, their perceptions toward the integrative approach, school context, delivery methods, and so on. That is, STEM teachers' decision to implement integrative approaches is associated with national curricula, educational trends, rewards, and supports within their specific school contexts (Rogers, 2003; Sahin, 2006; Zubrowski, 2002). As Zubrowski (2002) noted, for successful implementation, the integrative approaches require close collaboration among STEM teachers, STEM teachers' commitment to the integrative approach, and administrative support. A brief overview of some of the integrative efforts supporting STEM education is addressed in the following sections.

Integrative Efforts in Science Education:

The educators in science education have supported the idea of integration through design based learning (Cajas, 2001; Kolodner et al., 2003; Mehalik et al., 2008; Norton, 2007; Roth, 2001). For example, Fortus et al. (2005) examined whether the enactment of a Design-Based Science (DBS) unit supported students' efforts to construct and transfer new science knowledge and problem-solving skills to the solution of a new real-world design problem in a real-world setting. One hundred and forty-nine students participated in the DBS unit, and their understanding was assessed by identical pre-instructional and post-instructional written tests. They concluded that the students showed a significant increase in their science content knowledge. In addition, Riskowski et al. (2009) implemented an engineering design project focusing on water resources in an 8th grade science class. Students were exposed to either an engineering project (treatment) or a more traditional format (control), and their knowledge of water resource issues was evaluated using a pre-post assessment tool. They concluded that students showed statistically significant improvement in two areas—they displayed higher levels of thinking on open-ended questions and greater content knowledge. These are a couple examples of integrative efforts in science education that showed positive effects on student science learning.

Integrative Efforts in Technology Education:

The profession of technology education has provided design technology projects to provide a context in which students could apply the understandings they had developed in science, mathematics, and technology (Lewis, 2006; Venville et al., 2004; Zubrowski, 2002). Childress (1996) investigated whether technology, science, and mathematics (TSM) curriculum integration improved the ability of technology education students to solve technological problems. He examined student solutions to technological problems and whether the solutions were better in a quasi-experimental research group. He found that no significant difference between the experimental group and the control group existed. In 2000, Venville et al. investigated how integrated teaching/learning in science, mathematics, and technology could be described when it was implemented in a traditional, discipline-based school environment. They examined what happened to student learning as a result of integrated teaching. They found that the technology project, the Solar Boat, provided a context in which the students could apply the understandings they had developed in science, mathematics, and technology and enhanced the relevance of those understandings. Overall, the integrative efforts in technology education show that integrative approaches among STEM subjects provide students with the constructivist learning and teaching context.

Integrative Efforts in Engineering Education:

The engineering education profession has employed engineering design as a means of integrating STEM subjects (Apedoe et al., 2008; Sadler et al., 2000). Everett et al. (2000) described the results of the design process and the content of the first-year integrated program implemented by the College of Engineering at Texas A&M University. It provided undergraduate students with a foundation in engineering problem-solving, design, and teamwork that integrated the traditional fundamentals in mathematics and science. They concluded that through the integrated program "students not only know the mathematics and science but also actually understand why they need to know it" (p. 171). Cantrell et al. (2006) developed the Teachers Integrating Engineering into Science (TIES) program that included engineering design using a variety of interactive learning activities in order to engage a wide range of students. Results of assessments were disaggregated by gender, ethnicity, special education, and socio-economic level. This study concluded that typically low-achieving students, disaggregated by their ethnic minority status, improved more dramatically than did typically high-achieving students. They concluded that engaging students in engineering curriculum activities may diminish achievement gaps in science for some student populations. Integrative efforts in engineering education show that engineering design processes not only motivate students' learning in mathematics and science but also are beneficial to a variety of students with different characteristics.

Integrative Efforts in Mathematics Education:

Mathematics educators have provided evidence that integrative approaches among STEM subjects are effective and necessary for success in mathematics (Elliott et al., 2001; Judson & Sawada, 2000). For instance, Judson and Sawada (2000) implemented an action-search integration project that occurred in a junior high school. They investigated the impact of integrating mathematics into a science class on achievement in the math class. They found that students in the integrated science course attained high achievement on the statistics unit in math class. Elliott et al. (2001) conducted experimental research to investigate the effect of an interdisciplinary course called "Algebra for the Sciences" on students' critical thinking skills, problem-solving skills, and attitudes towards mathematics. They concluded that there was no significant difference in problem-solving skills between students in the interdisciplinary course and students in the college algebra course, but students in the interdisciplinary course had slightly larger gains in critical thinking and significantly higher positive attitudes toward mathematics. Integration of mathematics with science, technology, and engineering (STE) provides students with the context in which they can make meaningful connections between mathematics and STE subjects. Mathematics is already embedded in STE, and integrative approaches could bridge abstract concepts in mathematics to practices in STE.

Methodology

Meta-analysis, which was pioneered by Glass (1976), was employed to address the research questions of this study. Meta-analysis is a systematic methodology to synthesize the findings from existing empirical studies in order to shed light on the future development of the field (Glass, 1976; Johnson & Christensen, 2008; Livingston, 2008). Meta-analysis combines quantitative results of different investigations on a related topic (Glass, 1976; Light & Pillemer, 1982; Slavin, 1986) and provides effect sizes which represent each study's findings in the form of standardized mean differences (Higgerson, 2005; Lipsey & Wilson, 2001).

Data Collection

This study began with a comprehensive search of all pertinent databases. Educational Resources Information Center (ERIC) via EBSCO Host aided the main search of articles, with additional information from Wilson Web, Digital Dissertation, and Google Scholar. Ninety-eight studies investigating the effects of the integrative approaches among STEM subjects were identified in the initial search. A second screening was performed by scrutinizing the abstracts and texts of the journal articles and dissertations; however, many either did not provide empirical data to calculate the effect sizes or did not examine the effects of the integrative approaches on students' achievement. Therefore, finally, twenty-eight studies were selected to examine the effects of the integrative approaches among STEM subjects.

Criteria for Inclusion

The studies were identified from an initial reading of primary and secondary sources related to the effects of integrative approaches among STEM subjects on students' achievement and were included if they satisfied the following criteria:

(1) They study integrative efforts of STEM education, published between 1989 and 2009.

(2) They are searchable in ERIC database, Digital Dissertation, and Google Scholar using the limited search keywords "integrative curriculum", "integrated curriculum", "integration",

"science and technology education", "science and mathematics education", "mathematics and technology education", " science, technology, engineering, and mathematics education", "achievement", "learning", and so on. Due to the inconsistency in terminology in the integrative approaches among STEM disciplines, a variety of search terms were used in locating appropriate studies.

(3) They examine students' achievement and provide empirical quantitative findings.

Calculating Effect Sizes

Twenty-eight studies included in this meta-analysis provided the different research designs. Statistical data from each study were recorded, including mean scores, standard deviation, chi square, t-value, and p-value. These values were converted to an effect size metric by using the conversion formulas provided by Borenstein et al. (2007), DeCoster (2004), Glass (1977), K. R. White (personal communication, April 28, 2009), and Comprehensive Meta Analysis (CMA) version 2.0 as shown in Table 1. In a number of cases, the effect sizes across studies are bi-modal, so the use of overall mean effect size could be misleading and make the findings inappropriate. Therefore, an individual effect size was reported in order to present the effects of integrative approaches among STEM subjects. According to Cohen (1988), the guidelines for interpreting effect sizes are ES = 0.2 (small effect), ES = 0.5 (medium effect), and ES = 0.8 (large effect).

Results

The purpose of this study was to synthesize the findings from existing research on the effects of the integrative approaches among STEM subjects on students' achievement. The results of this study should be viewed with an understanding of some methodological limitations. One limitation comes from the procedure of meta-analysis itself. Only documentation provided by the primary authors was considered in the analysis. Another limitation is related to the number of studies included in the meta-analysis. The small number of studies could lead to inflation of the results and a tendency to overreach the conclusions. However, it was not possible to include a larger

Given Statistics Data	Formulas
Mean and Standard deviation in one group	$\dfrac{\bar{X}_{post} - \bar{X}_{pre}}{SD_{pre}}$
Mean and Standard deviation in each group (two groups posttest only)	$\dfrac{\bar{X}_E - \bar{X}_C}{SD_C}$
Mean and Standard deviation in each group (two groups pre-post tests)	$\dfrac{(\bar{X}_{post} - \bar{X}_{pre})_E - (\bar{X}_{post} - \bar{X}_{pre})_C}{\frac{SD_{pre\,C} + SD_{pre\,E} + SD_{post\,C}}{3}}$
Given Chi-square	$\dfrac{2r}{\sqrt{1-r^2}}$, $r = \sqrt{\dfrac{x^2}{n}}$
Given t-value	$t\sqrt{\dfrac{1}{n_E} + \dfrac{1}{n_C}}$
Given p-value	CMA
CMA: Comprehensive meta analysis software	

Table 1. Conversion statistical formulas used to calculate the effect sizes

Study	N	Grade Levels	Types of Integration	Achievement	Effect Size	Code
Allen (1993)	86	High school	M-S	M-S	M: 0.11 S: 0.15	C1-M C1-S
Apedoe et al. (2008)	271	High school	E-S	S	S: 0.31	C2
Barker & Ansorge (2007)	32	Elementary school	E-S-T	E-S-T	E-S-T: 2.95	C3
Bolin (1992)	41	High school	M-S-T	M-S	M: -0.11 S: -0.61	C4-M C4-S
Brusic (1991)	119	Elementary school	S-T	S	S: -0.24	C5
Childress (1996)	33	Middle school	M-S-T	T	T: -0.51	C6
Clayton (1989)	280	High school	M-S	M	M: 0.11	C7
Crates (1994)	32	College	M-S	M-S	M: 0.09 S: -0.58	C8-M C8-S
Dantley (1999)	25	College	S-T	S	S: 0.65	C9
Dugger & Johnson (1992)	Pre:392 Post:22 2	High school	S-T	T	T: 3.27	C10
Dugger & Meier (1994)	Pre: 85 Post: 59	High school	S-T	T	T: 2.80	C11
Elliott et al. (2001)	143	College	M-S	M	M: 0.31	C12
Fortus et al. (2005)	149	High school	E-S-T	S	S: 2.07	C13
Judson & Sawada (2000)	53	Middle school	M-S	M	M: 1.37	C14
Hill (2002)	337/ 334	Middle school	M-S	M	M: 0.13	C15
Lawrence (1997)	61	High school	M-S	M	M: 0.09	C16
Lam, et al. (2008)	21	Middle school	S-T-E-M	S-T-E-M	S-T-E-M: 1.76	C17
Mehalik, et al. (2008)	1053	Middle school	E-S-T	S	S:0.89	C18
Merrill (2001)	71	High school	M-S-T	T	T: -0.03	C19
O'Connor (1998)	47	High school	M-S	M	M: 0.03	C20
Paslov (2007)	134	Middle school	E-M	M	M: 0.03	C21
Riskowski et al. (2009)	126	Middle school	E-S-T	S	S: 0.43	C22
Ross & Hogaboan-Gray (1998)	139	High school	M-S-T	S	S: 0.92	C23
Satchwell & Loepp (2002)	539	Middle school	M-S-T	M-S	M: 0.23 S: 0.34	C24-M C24-S
Su (2006)	257	College	S-T	S	S: 1.18	C25
Sullivan (2008)	26	Elementary school	E-S-T	E-S-T	E-S-T: 0.66	C26
Trezise (1996)	182	Middle school	M-S	M	M: -0.08	C27
Wiltshire (1997)	63	High school	M-S	M-S	M: 1.05 S: 0.93	C28-M C28-S

E: Engineering; M: Mathematics; S: Science; T: Technology
C1 to C28: Case 1 to case 28
C1-M; Case 1-Mathematics; C1-S, Case 1-Science
E-M: Integration of engineering and mathematics; E-M-S-T: Integration of engineering, mathematics, science, and technology; E-S: integration of engineering and science; E-S-T: Integration of engineering, science, and technology; M-S: Integration of mathematics and science; M-S-T: Integration of mathematics, science, and technology; S-T: Integration of science and technology
Achievement: Achievement score provided by each study.

Table 2. Major features of twenty-eight studies

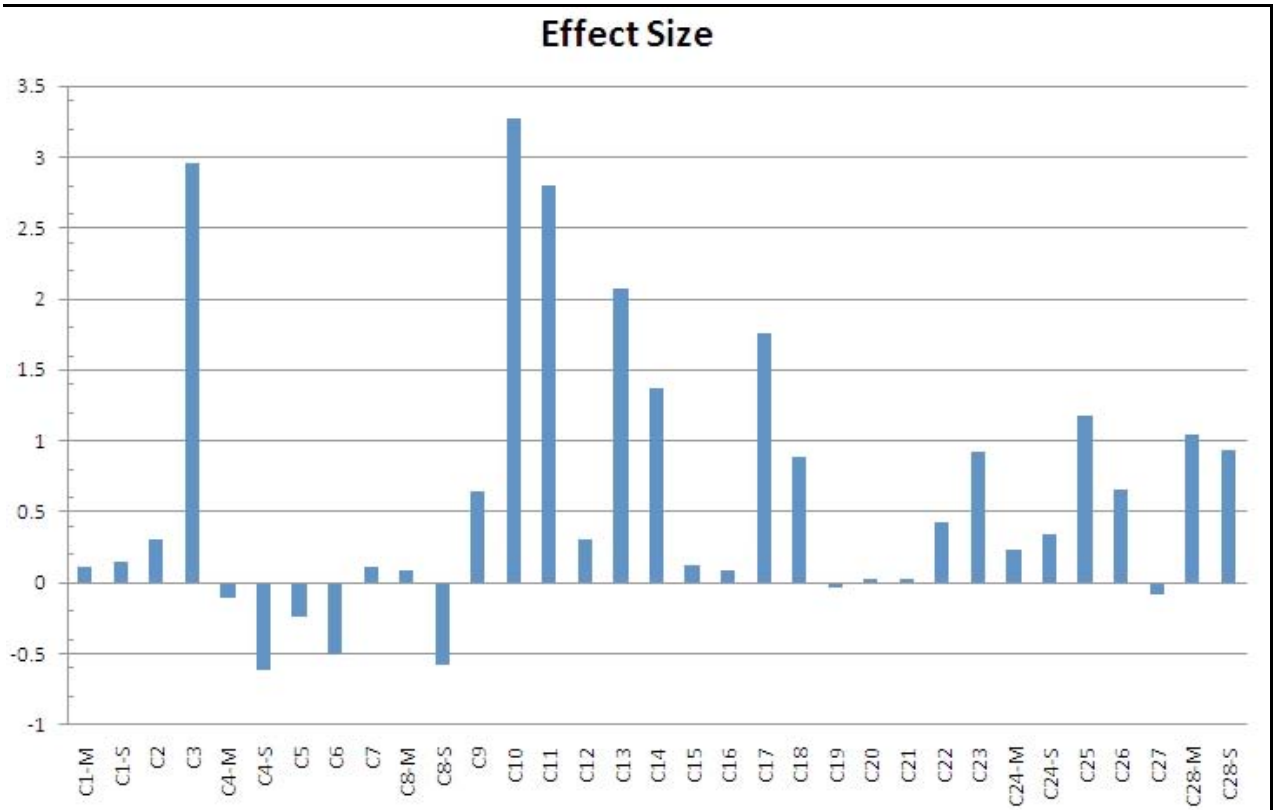

Figure 1. Thirty-three achievement effect sizes of twenty-eight studies

number of studies because numerous research studies in STEM education still remain in the form of opinion papers without empirical data. Few studies presenting quantitative evidence were available. For example, there was only one study that assessed the E-M-S-T achievement and provided quantitative data, and only two studies presented E-S-T achievement scores. The results of the meta-analysis are provided by addressing four research questions.

Research question number one addressed the effect of the integrative approaches among STEM subjects. Twenty-eight studies satisfied the criteria for this meta-analysis and a total of thirty-three achievement effect sizes were obtained for evaluating the effects of the integrative approaches among STEM subjects. Published articles and dissertations were used for the synthesis. The study sample sizes ranged from twenty-one to one thousand fifty-three students, representing grades from elementary through college. Table 2 displays the effect sizes and a summary of each study's characteristics.

Figure 1 shows the distribution of the effect sizes. The effect sizes ranged from 3.27 to -0.61. Eight studies (C3, C10, C11, C13, C14, C17, C25, C28-M) indicated the very large effect sizes of over 1.0, and eighteen studies (C1-M, C1-S, C2, C7, C8-M, C9, C12, C15, C16, C18, C20, C21, C22, C23, C24-M, C24-S, C26, C28) revealed the effect sizes of between 0 and 1.0. On the other hand, seven studies (C4-M, C4-S, C5, C6, C8-S, C19, C27) revealed the negative effect sizes. Effect size is the difference between the experimental and control group means divided by the control group standard deviation. Therefore, the negative effect size represents that the mean of the control group (traditional approach) is larger than the mean of the experimental group (integrative approach). Therefore, the negative effect size shows that the traditional approach outperformed the integrative approach.

Research question number two addressed how the effects of the integrative approaches among STEM subjects differed across grade levels. The effect sizes of twenty-eight studies are classified by grade levels in Table 3.

As shown in Table 3, the effect sizes of twenty-eight studies by grade levels are distributed by Cohen's (1988) guidelines interpreting effect sizes. Few studies reported specific ages of the participants, but most of studies reported the participant grade levels. Grade levels ranged from elementary to college. Three studies (11%) were conducted in elementary schools, 9

Grade Levels	Effect Sizes(ES)				Total # of Studies
	ES < 0.2	0.2<ES<0.5	0.5<ES<0.8	0.8<ES	
Elementary School	1		1	1	3
Middle School	4	2		3	9
High School	6	1		5	12
College	1	1	1	1	4

Table 3. Effect sizes of twenty-eight studies by grade levels

studies (32%) in middle schools, twelve studies (43%) in high schools, and four studies (14%) at the college level. The range of grade level indicates an integrative approach is potentially generalizable to elementary, secondary, and college students.

At the elementary school level, the study by Barker & Ansorge (2007) showed a very big effect size of 2.95 and the study by Sullivan (2008) presented a medium effect size of 0.66. However, the finding of Brusic (1991) showed the effect size of □0.24. At the middle school level, four studies (Childress, 1996; Hill, 2002; Paslov, 2007; Trezise, 1996) showed effect sizes of under 0.2. and the findings of Childress (1996) and Trezise (1996) showed negative effect sizes of □0.51 and □0.08 respectively. While two studies (Riskowski et al., 2009; Satchwell & Loepp, 2002) showed effect sizes of between 0.2 and 0.5., Mehalik et al. (2008) presented a relatively high effect size of 0.89. Then, Judson and Sawada (2000) and Lam et al. (2008) showed findings of the large effect sizes of 1.37 and 1.76. At the high school level, six studies (Allen, 1993; Bolin, 1992; Clayton, 1989; Lawrence, 1997; Merrill, 2001; O'Connor, 1998) showed effect sizes of under 0.2, and two out of six studies (Bolin, 1992; Merrill, 2001) reported negative effect sizes. Apedoe et al. (2008) showed a medium effect size of 0.31, Ross and Hogaboan-Gray (1998) showed a large effect size of 0.92, and Wiltshire (1997) showed the large effect sizes of 1.05 for mathematics and 0.93 for science. Three studies (Dugger & Johnson, 1992; Dugger & Meier, 1994; Fortus et al., 2005) showed very large effect sizes that were over 2.0. At the college level, four studies provided the effect sizes. Crates (1994) revealed a negative effect on science achievement (ES = □0.58) and a small effect on mathematics achievement (ES = 0.09). Elliott et al. (2001) showed a medium effect size of 0.31, Dantley (1999) showed a large effect size of 0.65, and Su (2006) showed a very large effect size of 1.18.

Research question number three questioned what type of integrative approaches was more likely than others to lead to the improvement of students' achievement. Table 4 presents the effect sizes of twenty-eight studies by the types of integration, distributed by Cohen's (1988) guidelines interpreting effect size.

All of the studies used the integrative approaches among STEM subjects, and the seven forms of integration (E-M, E-M-S-T, E-S, E-S-T, M-S, M-S-T, and S-T) were examined with the effect sizes for students' achievement. Ten studies (36%) used the integrative approach of mathematics and science (M-S). Five studies (18%) integrated engineering, science, and technology (E-S-T); five studies (18%) integrated mathematics, science, and technology (M-S-T); and five studies (18%) integrated science and technology (S-T). In addition, three studies were conducted using different types of integration: E-M (one study), E-M-S-T (one study), and E-S (one study).
Paslov (2007) showed a small effect size of 0.03 when integrating engineering and mathematics, and Apedoe and his colleague (2008) integrated engineering and science and showed a medium effect size of 0.31. However, Lam et al. (2008) showed a very large effect size of 1.76 by the integration of four subjects, E-M-S-T. Seven out of ten studies integrating mathematics and science (M-S) showed a very small effect size, and two studies (Judson & Sawada, 2000; Wiltshire, 1997) showed large effect sizes. In addition, five studies which integrated mathematics, science, and technology (M-S-T) revealed a small effect size and five studies integrating science and technology showed a very large effect size.

Types of Integration	Effect Sizes(ES)				Total # of Studies
	ES < 0.2	0.2<ES<0.5	0.5<ES<0.8	0.8<ES	
E-M	1				1
E-M-S-T				1	1
E-S		1			1
E-S-T		1	1	3	5
M-S	7	1		2	10
M-S-T	3	1		1	5
S-T	1		1	3	5

E-M: Integration of engineering and mathematics;
E-M-S-T: Integration of engineering, mathematics, science, and technology;
E-S: integration of engineering and science;
E-S-T: Integration of engineering, science, and technology;
M-S: Integration of mathematics and science;
M-S-T: Integration of mathematics, science, and technology;
S-T: Integration of science and technology

Table 4. Effect sizes of twenty-eight studies by the types of integration

Research question number four addressed which achievement score among STEM subjects was most improved through integrative approaches. Table 5 presents the effect sizes of students' achievement through integrative approaches.

As shown in Table 5, thirteen effect sizes (39%) reported mathematics achievement and thirteen effect sizes (39%) reported science achievement. One study (3%) assessed E-M-S-T achievement, two studies (6%) assessed E-S-T achievement, and four studies (12%) assessed technology achievement.

The study by Lam et al. (2008) showed a very large effect size of 1.76 when assessing E-M-S-T achievement. Two studies (Barker & Ansorge, 2007; Sullivan, 2008) revealed an E-S-T achievement with a very large effect size. These three studies assessed the integrative literacy among STEM subjects and showed very large effect sizes. Thirteen studies assessed mathematics achievement and presented a small effect size, and thirteen studies assessed science achievement and showed a medium effect size. However, the findings of four studies assessing technology achievement showed a very large effect size.

Conclusions

This study aimed at synthesizing the findings from existing research on the effects of the integrative approaches among STEM subjects on students' achievement. However,

Achievement	Effect Sizes(ES)				Total # of Studies
	ES < 0.2	0.2<ES<0.5	0.5<ES<0.8	0.8<ES	
E-M-S-T				1	1
E-S-T			1	1	2
M	9	2		2	13
S	4	3	1	5	13
T	2			2	4

E-M-S-T: EMST integrated achievement ; E-S-T: EST integrated achievement; M: Mathematics achievement; S: Science achievement; T: Technology achievement

Table 5. Effect sizes of students' achievement through integrative approaches

it is significant to note that this meta-analysis should be regarded as preliminary because there are very few empirical studies on the effects of integrative approaches among STEM subjects on students' learning. The conclusions based on this meta-analysis might be very exploratory and unconfirmed. However, as Mick, Biederman, Pandina, and Faraone (2003) noted, "while it is obvious that a primary goal of meta-analysis is to synthesize data from many different studies to describe some phenomenon with greater precision and power, a less appreciated goal of meta-analysis is to identify weaknesses in the literature and areas in need of further research" (p. 1025). The results revealed that integrative approaches among STEM subjects have a positive effect on the students' achievement. Based on the findings, further research and educational practice in STEM education are needed.

Discussion

Students who were exposed to integrative approaches demonstrated greater achievement in STEM subjects. Integrative approaches provide students with a rich learning context to improve student learning and interest (Riskowski et al., 2009). Students' interest and their positive attitude toward STEM fields could help improve motivation in their future STEM careers (Sanders, 2009). However, integrative approaches among STEM subjects have barriers to implementation. Teachers in STEM fields lack information on the benefits of integrative approaches, and school administrators do not regard integrative approaches as the ways to motivate students' learning in STEM subjects. Successful integration of STEM subjects may depend not only upon STEM teachers' committment to the integration, but also upon school administrators' support (Clark & Ernst, 2007). It is apparent that integrative approaches could be a motivator for teaching and learning STEM concepts and could provide cognitive benefits.

The effects of integrative approaches by grade levels indicated that early exposure may yield higher achievement scores among STEM subjects. These outcomes reflect that integrative approaches among STEM subjects may be better suited to young learners. Although the integrative approach is common practice at the college level, the empirical evidence shows that the effect on students' learning seems to be better at the lower level. According to Sanders (2009), "elementary grades offer unique opportunities for integrative approaches to STEM education and are absolutely the place to begin these integrative approaches. If America hopes to effectively address the 'STEM pipeline' problem, we must find ways of developing young learners' interest in STEM education and must sustain that interest throughout their remaining school years" (p. 22). In addition, elementary school teachers may have more flexibility in their curriculum and be more open to integrative approaches (Zubrowski, 2002). Integrative approaches at the secondary and college levels face challenges such as standardized testing, collaboration among STEM teachers, school structural limitation, and lack of instructional materials (Judson & Sawada, 2000; Zubrowski, 2002). Therefore, the low effects of the integrative approaches were shown at the secondary and college levels. However, integrative approaches in STEM education are worth implementing regardless of grade levels because students could benefit from the active student-centered learning context provided by integrative approaches.

Looking at the effects of integrative approaches by types of integration, when science and technology (S-T) were integrated into E-M-S-T, E-S-T, and S-T, the effect sizes were very large. However, it is interesting to note that the effect sizes of students' achievement were small when mathematics was integrated. The integration of M-S-T and E-M showed a very small effect size. Therefore, the type of integrative approaches implemented and the subjects used should be carefully considered. It would appear that integrative approaches could be implemented with different perspectives: as a content, as a method, or as a process (Childress & Laporte, 1997; Foster, 1997). For example, with the integration of science and technology, technology seemed to be integrated as a process that introduced students to the problem solving/design process so that students could understand scientific knowledge in the integrated context. The types of integration may be the key factor that impact the effects of the integrative approaches among STEM subjects.

Looking at students' achievement through integrative approaches, the findings revealed that students' achievement on the integrated concepts of STEM literacy showed large effect sizes. Science achievement presented a medium effect size and technology achievement showed a large effect size. However, not surprisingly, mathematics achievement showed a small effect size. Elliott (2001) noted that students' interest in STEM fields was improved by the integrative approaches and there was a positive relationship between students' attitudes towards mathematics and their achievement in mathematics. In addition, Farrior et al. (2007) noted that integrative approaches among STEM subjects could motivate students to see real-world applications of mathematics in STEM fields, even though students' achievement did not show the improvement in their study. By implementing the integrative approaches, students' achievements may be gradually improved along with their interests. The increased interest in mathematics may be more important than their achievement with regard to their future career choice in STEM fields.

Implications

This preliminary meta-analysis establishes a need for future research to empirically evaluate students' learning through integrative approaches among STEM subjects. More quantitative and qualitative research should be conducted to confirm the findings found in this preliminary meta-analysis. Teachers in K–16 could consider including integrative approaches in their curricula to provide students with a rich learning context in which students learn new knowledge among STEM subjects.

The findings obtained in this preliminary meta-analysis indicated that integrative approaches among STEM subjects made the STEM instruction more effective. In particular, the integrative approaches showed a high effect at the elementary school level. Elementary school teachers could consider incorporating integrative approaches among STEM subjects into their instruction. However, integrative approaches among STEM subjects are still effective at the secondary and college level (Dantley, 1999; Dugger & Johnson, 1992; Dugger & Meier, 1994; Fortus et al., 2005; Judson & Sawada, 2000; Mehalik et al., 2008; Su, 2006); thus, more research on the effects of integrative approaches by grade levels should be conducted to design effective instruction of STEM education with careful consideration of students' ages.

Future research needs to consider the possible differential effects of integrative approaches by the types of integration. Research on what type of integrative approaches is more likely than others to lead to the improvement of students' achievement should be conducted. Various types of integrative approaches could serve as bridges between the theoretical learning of mathematics and science and the practical learning of technology and engineering. This information may reduce teachers' efforts to implement integrative approaches among STEM subjects in their classroom and help them feel comfortable infusing the integrative approaches.

There has been limited research on the effects of integrative approaches among STEM subjects on students' mathematics achievement. It would be of interest to investigate why mathematics is the STEM subject that benefits least from integrative approaches. In order to enhance the students' learning of mathematics through integrative approaches, continued examination of how mathematic concepts are developed through the integration approaches should be explored. This information may help teachers and professionals in STEM fields be aware of the benefits of integrative approaches among STEM subjects.

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