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Kadir Kozan
Purdue University, kkozan@purdue.edu

Secil Caskurlu
Florida State University, scaskurlu@fsu.edu

Siddika Selcen Guzey
Purdue University, sguzey@purdue.edu

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Keywords

engineering education, integrated STEM, K-12 education, student outcomes, systematic review

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Factors Influencing Student Outcomes in K-12 Integrated STEM Education: A Systematic Review

Kadir Kozan[1], Secil Caskurlu[2], and Siddika Selcen Guzey[1]

[1]Purdue University
[2]Florida State University

Abstract

Earlier integrated science, technology, engineering, and mathematics (STEM) education research has shown effects on students' attitudes toward STEM careers, actual and perceived learning, and interest in pursuing a STEM career in their future endeavors. The current systematic review purported to review the recent K-12 integrated STEM education research to determine (a) the factors that influence student outcomes and (b) the general characteristics of reviewed studies. Overall, the results (a) showed that most studies focused on integrating at least three subject areas; (b) highlighted four main factors (i.e., instructional, teacher-related, student-related, and extracurricular factors) that jointly influence student outcomes; and (c) revealed that science is the most frequently integrated main field followed by engineering. Engineering also turned out to be a connector in integrated STEM together with technology. The results led to various implications for both in-class practice and future research on K-12 integrated STEM education.

Keywords: engineering education, integrated STEM, K-12 education, student outcomes, systematic review

Introduction

Integrated science, technology, engineering, and mathematics (STEM) has gained increasing attention in K-12 education in both formal and informal learning settings due to its impact on various student outcomes (e.g., Burrows et al., 2014; Fan & Yu, 2017) including actual learning or perceived learning (e.g., Sinatra et al., 2017), making connections across STEM subjects (e.g., National Academy of Engineering [NAE] & National Research Council [NRC], 2009, 2014), and students' attitudes toward STEM and their interest in both STEM content and careers (e.g., Blackley et al., 2018). There is a need for carefully planning integrated STEM experiences based on various elements such as learning experience design (e.g., Honey et al., 2014), teacher professional development for facilitation of integrated STEM (e.g., Lambert et al., 2018), and explicit integration of integrated STEM in K-12 (e.g., Honey et al., 2014).

Previous research has also presented instructional strategies to enhance STEM education such as (a) employing contextual factors (e.g., authentic or real-life contexts including hands-on inquiry-based approaches; e.g., Hirsch et al., 2017) and (b) integrating real-world-related engineering design challenges (e.g., Dare et al., 2017). Likewise, earlier review studies focused on various aspects of STEM education including but not limited to trends and research (e.g., Li et al., 2020), teacher perceptions (e.g., Margot & Kettler, 2019), STEM education practices (e.g., Rahman et al., 2021), and instructional practices (e.g., Thibaut et al., 2018). We further need to know the factors impacting student outcomes in K-12 integrated STEM education in tandem with the characteristics of research identifying them thus developing a more comprehensive understanding for both researchers and practitioners, which is addressed by the current review. Lastly, different from most

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earlier reviews, the research characteristics addressed in this review cover not only the number of integrated STEM fields but also the main or focus area, which provides direct insights into the way in which STEM fields have been integrated into learning experiences.

Specifically, given the importance of what is learned in earlier grades for future learning, focusing on the factors influencing student outcomes in integrated STEM education in K-12 is crucial. Similarly, because (a) "the best evidence about the effectiveness of education products, programs, policies, and practices" is important for educational decision making (U.S. Department of Education, n.d., p. 1) and (b) trustworthiness of research purporting to examine causal and effect relations depends significantly on research design (Gorard, 2014), it is equally important to gain insights into the characteristics of research reporting those factors. To this end, the present study reviews recent integrated STEM implementation studies in K-12 to identify the main success factors influencing student outcomes and to describe the general characteristics of the reviewed research.

Definitions of Integrated STEM in K-12 Education

Integrated STEM is to develop learning experiences that integrate more than one STEM field and where students are engaged in the scientific inquiry process to make connections between STEM fields (Honey et al., 2014; Pearson, 2017). In this context, (a) science is defined as "the study of the natural world, including the laws of nature associated with physics, chemistry, and biology and the treatment or application of facts, principles, concepts, or conventions associated with these disciplines" (Honey et al., 2014, p. 14); (b) technology "comprises the entire system of people and organizations, knowledge, processes, and devices that go into creating and operating technological artefacts, as well as the artefacts themselves" (Honey et al., 2014, p. 14); (c) engineering refers to "both a body of knowledge—about the design and creation of human-made products—and a process for solving problems" (Honey et al., 2014, p. 14); and (d) mathematics is "the study of patterns and relationships among quantities, numbers, and space" (Honey et al., 2014, p. 14).

There is a strong call for teaching STEM in an integrated manner since STEM disciplines "share many big ideas, conceptual structures, and practices that, when integrated, allow students to apply their knowledge in an array of ways and make connections that allow them to transfer across disciplines" (Moore et al., 2020, p. 5). Integrated STEM learning experiences provide students opportunities for gaining new skills related to STEM disciplines and skills that they cannot acquire in individual disciplines, and applying those skills to solve complex problems (Moore et al., 2020). Yet, the definition and conceptualization of integrated STEM are still varied (e.g., Nadelson & Seifert, 2017). As shown in Table 1, the definition of integrated STEM ranges from integrating more than one field (e.g., Blackley et al., 2018; Dare et al., 2018) to using real-life-related engineering design challenges to connect STEM fields (e.g., STEM Task Force Report, 2014).

Similarly, there are various conceptualizations of integrated STEM. To illustrate, Bybee (2013) addressed five conceptualizations of integrated STEM: (a) use of science and mathematics as main disciplines and incorporating engineering or technology as examples/learning activities; (b) coordinating concepts, processes, and resources across disciplines; (c) making STEM as the main focus of the learning experience by sequencing disciplines in units or courses; and (d) creating transdisciplinary learning experiences by using STEM and other disciplines to "understand a major contemporary challenge" (p. 78).

The variety of definitions and conceptualizations of integrated STEM may lead to uncertainty in "the degree to which disciplines are integrated or how specifically that integration should be structured within schools or classrooms" (Moore et al., 2020, p. 11). Consequently, to move forward with integrated STEM research and practice, a common understanding of the definition and conceptualization of integrated STEM is needed (Holmlund et al., 2018; Johnson, 2013; Moore et al., 2020).

Implementation of Integrated STEM in K-12 Education

Research on integrated STEM education highlighted several general features of effective STEM learning experiences. First, arguing that STEM integration should be explicit, previous research has widely used "problem-, project-, or design-based tasks to engage students in addressing complex contexts that reflect real-world situations" (Honey et al., 2014, p. 51) (e.g., Dare et al., 2017). The results of previous studies showed that such integrated learning experiences foster students' 21st century skills, increase students' attitude toward STEM subjects and pursuing a STEM-related career, and increase students' motivation toward learning (e.g., Blackley et al., 2018; Burrows et al., 2014; Fan & Yu, 2017; Hernandez et al., 2014; Wan Husin et al., 2016; Wilhelm et al., 2013; Zeng & Sundaram, 2011). Second, supporting students' knowledge and skills in different fields and providing scaffolding to students during the learning process are essential for effective integrated STEM learning experiences (e.g., Fan et al., 2018; Hudson et al., 2015; McFadden & Roehrig, 2019; Savard & Freiman, 2016; Toma & Greca, 2017; Valtorta & Berland, 2015). Thus, teacher knowledge, confidence, and familiarity with STEM concepts as well as integrated approaches are important for effectively implementing integrated STEM (e.g., Aldemir & Kermani, 2017; Ntemngwa & Oliver, 2018; Robinson III et al., 2014; Yoon et al., 2014). Finally, previous

Table 1
Definitions of integrated STEM.

Author(s)	Integrated STEM definition
*Baran et al. (2016)	"an effort by educators to have students participate in engineering design as a means to develop technologies that require meaningful learning and an application of mathematics and/or science (Moore et al., 2014, p. 38)" (p. 10).
*Blackley et al. (2018)	"intentional integration of two or more of the disciplines (science, technology, engineering, mathematics), and potentially with other learning areas, with a focus on authentic problem solving (Sanders, 2009) or product creation, including the application of an engineering design process (e.g. brainstorming, creating, testing improving)" (p. 23).
*Dare et al. (2018)	"an effort to combine some or all of the four disciplines of science, technology, engineering, and mathematics into one class, unit or lesson that is based on connections between the subjects and real world problems" (p. 38).
*Guzey et al. (2017)	"the merging of the disciplines of science, technology, engineering, and mathematics in order to (a) deepen student understanding by contextualizing concepts, (b) broaden student understanding through exposure to socially and culturally relevant STEM contexts, and (c) increase interest in STEM disciplines and expand the pathways for students to enter STEM fields (Guzey et al. 2014; Moore et al. 2014)" (p. 207). "the use of engineering design and practices as a vehicle to teach science and mathematics" (p. 207).
*Hynes et al. (2016)	"STEM integration research paradigm, which is defined by the merging of the disciplines of science, technology, engineering, and mathematics in order to: (1) deepen student understanding of STEM disciplines by contextualizing concepts, (2) broaden student understanding of STEM disciplines through exposure to socially and culturally relevant STEM contexts, and (3) increase student interest in STEM disciplines to expand their pathways for students entering STEM fields (Roehrig, Moore, Wang & Park, 2012)" (para. 8).
*John et al (2016)	"technological/engineering design-based learning approach that intentionally integrates the concepts and practices of science and/or mathematics education with the concepts and practices of technology and engineering education" (p. 1).
*Lambert et al. (2018)	"application of technological/ engineering design based pedagogical approaches to intentionally teach content and practices of science and mathematics education through the content and practices of technology/engineering education (Wells & Ernst, 2012/2015)" (para. 3).
Nadelson & Seifert (2017)	"as the seamless amalgamation of content and concepts from multiple STEM disciplines. The integration takes place in ways such that knowledge and process of the specific STEM disciplines are considered simultaneously without regard to the discipline, but rather in the context of a problem, project, or task" (p. 221).
*Ntemngwa & Oliver (2018)	"a pedagogical approach in which concepts and objectives from two or more STEM disciplines are incorporated into a single project. Further this integration exposes students to the connections among and across these concepts and/or practices, and supports learning and/or application of the concepts simultaneously rather than in isolation" (p. 12).
*Robinson III et al. (2014)	"incorporate two or more of the STEM subject areas in the instruction of a general STEM concept" (para. 20).
*Tank et al. (2015)	"uses engineering, which requires purposeful and meaningful understanding and application of mathematics and science through the use and development of relevant technologies" (p. 14).
*Valtorta & Berland (2015)	"connecting across the concepts found in different disciplines" (p. 16).

research has noted that successful implementation of integrated STEM is a collaborative work of teachers, administrators, and parents (e.g., Robinson III et al., 2014; Shahali et al., 2017), and requires meaningful and purposeful integration of integrated STEM in K-12 (e.g., Honey et al., 2014).

Overall, earlier research suggests that positive effects of K-12 integrated STEM education on student outcomes depend on some factors, and a comprehensive understanding of these factors and the research on them would provide rich insights into both practice and future research. In this regard, this systematic review study provides a comprehensive overview of previous studies thereby identifying the factors that influence student outcomes in K-12 integrated STEM education and the general characteristics (e.g., data sources, participant characteristics, data analysis, etc.) of the research that were revealed, thereby addressing the following complementary research questions:

- What are the main factors that influence student outcomes in K-12 integrated STEM education as suggested by the reviewed research?
- What are the general characteristics (i.e., integrated STEM fields, main integrated field, research method, data sources, grade level, number of participants, and data analysis) of the primary K-12 integrated STEM education research reviewed in this study?

Methods

Search Process

The target population consisted of studies published from 2008 to 2021. Electronic databases (i.e., EBSCO, PsycINFO, ERIC, and Education Full Text) and search engines through the university library's website and Google Scholar were used

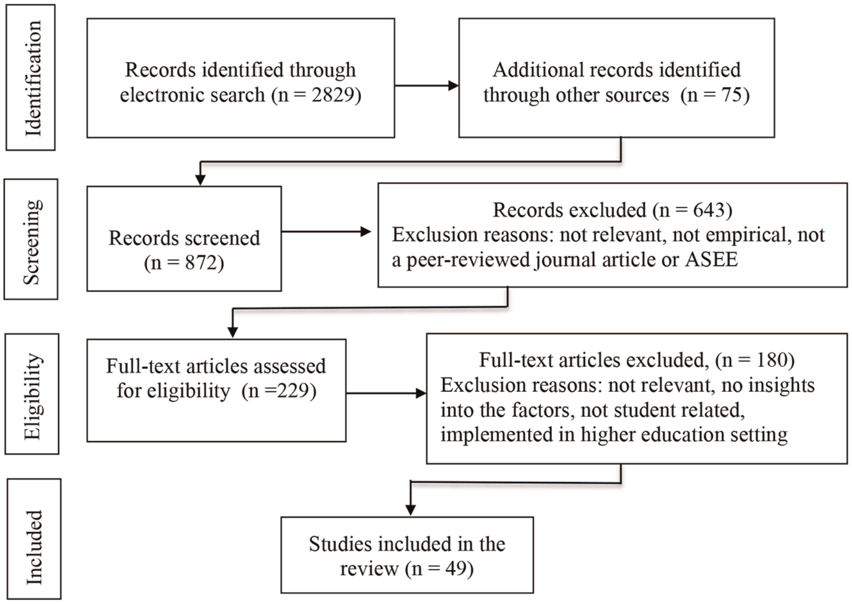

Figure 1. Search process.

to search for relevant studies based on the following keywords: *integrated STEM*, *integrative STEM*, *science integrated STEM*, *technology integrated STEM*, *engineering integrated STEM*, and *mathematics integrated STEM*. We also conducted (a) a manual search by reviewing the reference sections of the primary studies; (b) a hand search of relevant journals (i.e., *Journal of Engineering Education*, *International Journal of STEM*, *Journal of Science Education and Technology*, *International Journal of Science and Mathematics Education*, *International Journal of Engineering Education*) through accessible hard or electronic copies; (c) a search by the names of well-known or established researchers in the field of K-12 integrated STEM research; and (d) a search of proceedings from American Society of Engineering Education (ASEE) since these flagship conference proposals go through several rounds of a critical review process similar to journal articles. Figure 1 represents the search process.

Inclusion and Exclusion Criteria

To be included, a study had to (a) be empirical; (b) explicitly state and use integrated/integrative STEM as an educational approach; (c) be implemented with K-12 students; (d) provide insights into the implementation of integrated STEM; and (e) be published in a peer-reviewed journal or as a proceeding by ASEE in English. However, we excluded studies based on the clarity/transparency of information reported (e.g., data collection and analysis procedure, participant profile, setting, type of STEM integration, and main STEM field focus) to make proper interpretations to enhance the credibility of review results without having to guess any crucial information. Based on these criteria, of the identified 229 studies, 49 studies were included in this review.

Coding and Data Extraction

We first developed an initial coding schema including the following variables: integrated fields, main focus, research method, data sources, grade level, number of participants, data analysis, and important factors. Second, the coding schema was piloted on five sample studies. After finalizing the coding schema, two of the researchers coded all studies individually. Disagreements were resolved by discussing them all in the research group. In other words, the discrepancies in coding between the two coders were identified and discussed by the entire team. Initial inter-coder reliability was 81.91%. Any disagreements on coding were resolved and the final rate of coding agreement and accuracy reached 100%. We created the important factors inductively through open coding (Saldaña, 2016). First, the first and second authors identified the factors addressed in the included studies (e.g., project-based learning, situated cognition, working in groups, students' prior knowledge). After the first and second authors had coded all studies individually, we held group discussions to group and organize the important factors using the constant-comparison method.

Results

Primary Study Characteristics

Of the 49 studies (Appendix) included in this review, 18 were qualitative, 16 were quantitative, 11 were mixed method, two were action research, and two were design-based research. Thirty studies involved all four fields, 12 studies integrated three fields, and seven studies integrated two fields only. Specifically, 47 studies incorporated science, and science was the only single main focus area of 16 studies in addition to 11 studies that included science as one of the main fields integrated. Engineering was the main area in 15 studies and technology was in two studies while mathematics turned out to be the main area of one study. Finally, computational thinking was the main area integrated in one study while engineering and technology were integrated as main areas in two studies.

Factors that Influence Student Outcomes in K-12 Integrated STEM Education

The present review revealed four themes: instructional, teacher-related, student-related, and curricular factors. Namely, we were able to categorize our findings into the following four factor types.

Instructional Factors

The review of previous studies showed that being purposeful while designing and facilitating is essential for effective integrated STEM learning experiences (e.g., Tank et al., 2015). Therefore, this section focuses on the factors that are related to design and facilitation of integrated STEM learning experiences. The reviewed studies addressed instructional factors in relation to instructional approaches and strategies employed in an integrated STEM learning experience.

Instructional approaches. The current results indicated that the vast majority of included studies used the following instructional approaches: inquiry-based learning (e.g., Baran et al., 2016; Burrows et al., 2018; Wolf et al., 2020), situated cognition (e.g., Hernandez et al., 2014), and problem- and/or project-based learning (e.g., Baran et al., 2019; Ching et al., 2019; Dasgupta et al., 2019; Ntemngwa & Oliver, 2018; Wan Husin et al., 2016) that are all in tandem with active instructional strategies. The instructional strategies below provide further details into how these approaches were employed in the studies covered in this paper.

Instructional strategies. The current review revealed that explicit integration of instructional strategies is essential for effective learning experiences. In this sense, using authentic and real-life-related engineering design challenges, where students are engaged in scientific inquiry by collecting and analyzing data, developing a prototype, and evaluating their design decisions through an iterative process, is one of the most common instructional strategies employed in previous research (e.g., Burrows et al., 2014; Ching et al., 2019; Dare et al., 2017; Dasgupta et al., 2019; English, 2019; English et al., 2017; Fan et al., 2018; Fan & Yu, 2017; Guzey et al., 2016b; Hernandez et al. 2017; Ng & Chan, 2019; Sinatra et al., 2017; Yaki et al., 2019).

Crotty et al. (2017) noted that, "authentic learning activities, in which engineering practices are incorporated beyond superficial applications, are necessary for situated cognition to be most effective" (p. 10). Implementing such authentic activities can include use of authentic problems and projects under the umbrella of problem- and/or project-based learning as well. Additionally, previous research has shown that incorporating authentic learning experiences, specifically engineering-related design cases, increases students' knowledge and skills in STEM fields (e.g., Baran et al., 2019; Blackley et al., 2018; Burrows et al., 2014; Dare et al., 2017; Dasgupta et al., 2019; Fan & Yu, 2017; Ng & Chan, 2019; Robinson III et al., 2014; Sarican & Akgunduz, 2018; Sinatra et al., 2017; Tank et al., 2015; Wilhelm et al., 2013) and engagement in integrated STEM learning experiences (Blackley et al., 2018; Dasgupta et al., 2019; Sinatra et al., 2017; Zeng & Sundaram, 2011), attitude toward STEM (Burrows et al., 2014; Hsu et al., 2017; John et al., 2016; Toma & Greca, 2017) and pursuing a STEM career (Baran et al., 2019; Dare et al., 2017; Hsu et al., 2017; John et al., 2016; Zeng & Sundaram, 2011), helps them make connections across fields (Dare et al., 2017; Hernandez et al., 2014), changes their attitude toward what an engineer does (Guzey et al., 2016b; Hirsch et al., 2017), enhances 21st century skills (Blackley et al., 2018; Sheffield et al., 2017; Wan Husin et al., 2016), and helps them make connection between school work and daily life (Baran et al., 2019; Dare et al., 2017).

Earlier research has also pointed to the importance of working in teams and cooperation in integrated STEM units where engineering design challenges are used to integrate different fields (e.g., Aldemir & Kermani, 2017; Baran et al., 2016; Blackley et al., 2018; Ching et al., 2019; Dare et al., 2017; English, 2019; English et al., 2017; Hirsch et al., 2017; Hynes et al., 2016; Kopcha et al., 2017; Marks et al., 2021; Ntemngwa & Oliver, 2018; Sinatra et al., 2017; Tank et al., 2015;

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Wolf et al., 2020). In addition, previous studies also highlighted the importance of working in heterogeneous (Hirsch et al., 2017; Yaki et al., 2019; Zheng & Sundaram, 2011) and cross-functional STEM groups (Hernandez et al., 2014). However, there were findings indicating that group work was not easy due to the lack of agreement between team members (e.g., Ching et al., 2019). These insights suggest implementing heterogeneous and cross-functional group work items despite possible challenges that disagreements among such diverse group members can cause, thereby referring to a reasonable trade-off.

Instructional scaffolding. The review results revealed that scaffolding is also essential for effective integrated STEM learning experiences to help students make connections across disciplines (Valtorta & Berland, 2015), and conceptualize the concepts and the given tasks (e.g., Blackley et al., 2018; Fan et al., 2018; Glancy et al., 2017; Hudson et al., 2015; McFadden & Roehrig, 2019; Ng & Chan, 2019; Toma & Greca, 2017; Wolf et al., 2020).

Still, Valtorta and Berland's (2015) study highlighted that explicit support on STEM concepts may not be enough for effective integration, and teachers may also "create situations that help students recognize the need for that content" (p. 28). In this respect, Hudson et al.'s (2015) findings suggested that providing students with resources (e.g., job aids) and questioning them during activities also increase students' motivation into the tasks, and guide them while understanding the concepts and reflecting on their work.

Consequently, this section concluded that using authentic and real-world-related engineering design challenges is helpful to make integrated STEM explicit. Also, working in groups, especially in heterogeneous groups, seems to be effective for students. Finally, scaffolding during the integrated STEM learning experiences is essential to ensure students achieve the learning outcomes.

Teacher-Related Factors

The current review indicated that teacher knowledge, confidence, and familiarity with STEM concepts (e.g., Aldemir & Kermani, 2017; Dare et al., 2018; Lambert et al., 2018; Ntemngwa & Oliver, 2018; Robinson III et al., 2014; Toma & Greca, 2018; Yoon et al., 2014), teachers' prior experience with integrated approaches (e.g., Ntemngwa & Oliver, 2018), and teachers' beliefs and interest in STEM (e.g., Aldemir & Kermani, 2017) are important for effective integrated STEM education in K-12. Thus, it seems to be essential to provide professional development opportunities and sustained support to teachers (e.g., Aldemir & Kermani, 2017; Lambert et al., 2018; Ntemngwa & Oliver, 2018). After all, some participating teachers in reviewed studies "never thought the topic of engineering could be implemented with Pre-K children" (Aldemir & Kermini, 2017, p. 1703) as well as noting that participating in a professional development before implementing an integrated STEM unit helped them understand the concepts and integrate and implement the STEM-related activities in a meaningful way. Supporting these findings, in Lambert et al. (2018), teachers reported that, after their participation in professional development activities on integrated STEM, student content knowledge increased in integrated STEM lessons. Accordingly, it is important to support teachers to become competent in STEM concepts and their integration.

Student-Related Factors

The current results revealed factors that are directly related to students. These included student characteristics (e.g., students with special needs, grade level; e.g., Guzey et al., 2016a, 2017), student prior knowledge (e.g., Blackley et al., 2018; Fan & Yu, 2017; Hudson et al., 2015; Moreno et al., 2016; Savard & Freiman, 2016; Yoon et al., 2014), content knowledge (e.g., Fan et al., 2018; Glancy et al., 2017; Marks et al., 2021), academic achievement (e.g., Yaki et al., 2019), and student perceptions about STEM activities (e.g., Baran et al., 2016). To illustrate, Fan et al. (2018) showed that students' conceptual knowledge, metacognitive skills, and interest in the task influence their approach to an engineering design challenge as well as the complexity of the solution.

Although students participating in integrated STEM emphasized their engagement, demonstrated higher learning outcomes, and showed a positive attitude toward STEM subjects and STEM-related careers, exceptions were reported in the included studies (e.g., Ching et al., 2019; Ortiz et al., 2017; Shahali et al., 2019; Yoon et al., 2014). In their quasi-experimental study, Yoon et al. (2014) found that even though students in an engineering integrated curriculum unit scored significantly higher than the students in the control group, their perceptions of themselves academically did not differ from the control group. The authors noted that students might not be "ready to assess their own beliefs about their academic performance" (p. 387). Likewise, in Ortiz et al.'s (2017) mixed methods study, even though some students commented that they learned what an engineer does after participating in an integrated STEM unit in a summer camp, there was no significant difference in students' interest in pursuing engineering-related careers after participating in the integrated STEM unit. In their longitudinal study, Shahali et al. (2019) also found that even though students' interests in STEM subjects increased after participating in Bitara-STEM program, their interest significantly decreased two years after leaving the program.

Extracurricular Factors

Previous research has suggested participating in extracurricular activities (e.g., summer enrichment programs, after-school programs, and community projects) based on such arguments as "engineering principles and applications of the engineering design process" is missing in middle school curriculum (Hirsch et al., 2017, p. 405). Such activities can be more flexible than traditional classrooms that are based on mandatory activities and timing (e.g., Burrows et al., 2018; Ching et al., 2019; Hirsch et al., 2017; Moreno et al., 2016; Shahali et al., 2017; Wolf et al., 2020). However, previous research has also demonstrated mixed results on the effectiveness of participating in such programs on student outcomes. For instance, in their quasi-experimental study, Moreno et al. (2016) found that students who participated in after-school programs showed significantly higher content knowledge gains than their peers who did not participate; however, participants' attitudes toward science did not significantly improve. On the other hand, the results of Hirsch et al. (2017) showed that similar programs not only helped students to make connections across disciplines but also increased their attitudes toward pursuing a STEM career and clarified their understanding of what an engineer does. In their quasi-experimental study, Shahali et al. (2017) also found that participating in an extracurricular activity increased students' interest in pursuing STEM careers and disciplines.

Discussion

General Characteristics of Reviewed K-12 Integrated STEM Research

The review of included studies showed that science is the most commonly used main focus area in integrated STEM units followed by engineering. This finding suggests that science has an important or dominant place in integrated STEM education. Engineering is second only to science as the main focus area in integrated STEM. This finding is not surprising given the focus of Next Generation Science Standards on connecting science and engineering and including engineering-related learning objectives (NGSS Lead States, 2013). The results also showed that mathematics was the main integrated field in only one of the included studies. Aligning with previous research, the results of this review suggested that mathematics in integrated STEM research needs more attention (English 2017; Stohlmann, 2018) and the role of mathematics should be beyond mathematical modeling and using mathematical technology programs (Stohlmann, 2018). In a review on mathematics in STEM, Stohlmann (2018) found that measurement, data analysis, geometry, and linear and quadratic equations were the most common mathematical content in the STEM studies. Thus, future research should focus on including mathematical content that aligns with standards. In addition, curricular efforts on integrated STEM should highlight the connection between and among integrated STEM disciplines thereby indicating how integrated STEM learning experiences make the learning explicit in each integrated field (English, 2017).

Furthermore, confirming Honey et al. (2014), this review also showed that engineering and technology were used through collaborative authentic learning activities to make connections between STEM fields (Kelly & Knowles, 2016). In other words, engineering- and technology-related authentic learning activities functioned as bridges among STEM fields. Even though all these insights seem to suggest an implicit hierarchy among STEM fields, such a hierarchy appears to be immersed in authentic learning activities in which integrated STEM provides an integrated context to learn each STEM field. That is also why there seems to be an emphasis on purposeful design and explicit integration of STEM fields: most of the studies reviewed here included integration among four fields, then three, and finally two.

It is also important to note how previous research handled especially technology and engineering that seems to have functioned as a sort of glue among STEM fields. For instance, one aspect of technology in integrated STEM focuses on "the artifacts themselves" (Honey et al., 2014, p. 14), and the vast majority of the studies included in this review also considered technology as a student product. However, Honey et al. (2014) provided a larger conceptualization of technology in which technology bears a systemic value in that it refers to the overall performance system including various components, one of which is technological tools or products. This larger approach to technology also aligns with Stolovitch and Keeps's (2004) definition of technology that covers the application of both scientific and professional knowledge with the purpose of solving performance problems. Accordingly, it seems that integrated STEM research and practice may focus on larger conceptualizations of technology, which may lead them to focusing on not only the products themselves but also their associated processes, and this approach may align more with engineering design thinking.

Even though the integration of STEM fields has been achieved to some extent in learning activities or experiences, assessment or evaluation of learning outcomes may not be fully integrated. Specifically, the review of studies showed that actual/conceptual learning is mainly measured by achievement tests that focused on individual fields rather than integrated knowledge. One explanation for this finding could be related to the lack of a "widely accepted definition of integrative thinking" (Honey et al., 2014, p. 52). Therefore, more discussion on what integrative thinking is and in what forms integrated

STEM can actually happen seems to be necessary, which can more clearly inform both integrated STEM education and the research on it. Speaking of research, the current review mostly included qualitative and quantitative studies. Running more and different research ranging from design-based research to action research in authentic learning contexts would provide richer insights. After all, earlier research highlighted the role of authentic learning experiences in integrated STEM, which can be complemented by running research in authentic learning contexts through various research methods.

Factors that Influence Student Outcomes in K-12 Integrated STEM Education

The present systematic review also aimed to determine the factors that influence student outcomes in K-12 integrated STEM education research. The results of the review suggested that creating effective integrated STEM learning experiences requires further planning based on a number of interrelated factors (i.e., instructional, teacher-related, student-related, and curricular factors) as well as other small-scale factors. As they are reported here, the relationships among these factors are just descriptive, not directional (Figure 2).

First, the results of this review identified various instructional strategies for effective integrated STEM education at K-12 level ranging from employing authentic design tasks to small groups. This finding highlights an active learning approach in integrated STEM education that means keeping learners cognitively active by questioning, designing, restarting if necessary, evaluating, and the like. However, based on our findings, it is difficult to say whether one specific strategy is better than any other one due to the lack of true experimental studies even though the number of empirical studies have been increasing in STEM education research recently (e.g., Li et al., 2020). Given especially the active nature of science, engineering, and technology when it comes to problem solving in human life, the focus on active learning activities or strategies is not surprising. It is important to note that mathematics is also crucial for problem solving through science, engineering, and technology since all these three fields depend largely on mathematics while designing and running solutions.

Further, in line with previous research, the current results also showed that teachers' knowledge, confidence, and interest in integrated STEM and STEM fields (e.g., Honey et al., 2014; Kelly & Knowles, 2016; Nadelson & Seifert, 2017) as well as teacher professional development (e.g., Aldemir & Kermini, 2017; Lambert et al., 2018) are also important for effective K-12 integrated STEM education. Thus, the implication here is that we are in need of continuous teacher support and professional development to support teachers, and to achieve sustainable and successful integrated STEM practice. More specifically, such efforts can focus on (a) establishing teachers' content knowledge of each STEM field; (b) helping teachers make connection between and among disciplines; (c) providing worked examples that demonstrate what meaningful integrated STEM learning experiences look like in practice; and (d) co-designing integrated STEM learning experiences with teachers. In other words, future integrated STEM teacher professional development opportunities can be integrated into teachers' professional practice in a collaborative way. Some existing professional development approaches can also be used to enhance these efforts. For instance, Barab et al.'s (2006) embedded professional development approach puts teacher learning into real-life applications or practices through collaborative and individual reflections. This approach consists of multiple components including (a) formal (e.g., trainings) and informal (e.g., conversations or chats during teaching practices) experiences; (b) individual and collaborative reflections; and (c) traditional (e.g., readings) and innovative (e.g., gamification) curriculum. Likewise, teacher learning communities (e.g., Falkner et al., 2018) or teacher study groups (e.g., Gersten et al., 2010), and collective teacher efficacy (e.g., Goldhaber et al., 2019) can be added to such an active

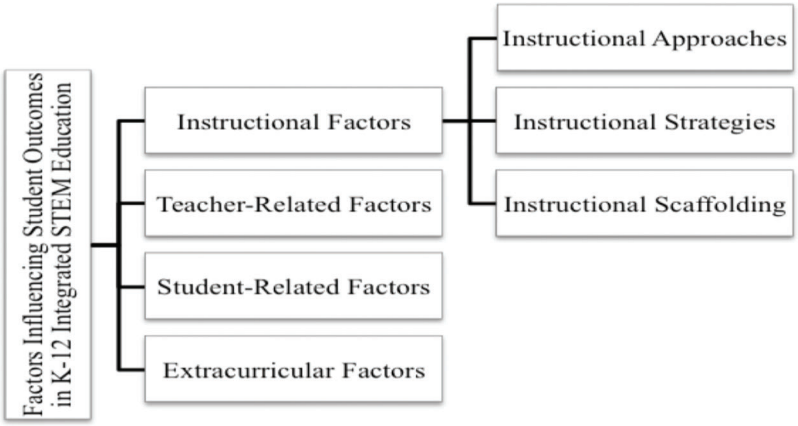

Figure 2. Factors influencing student outcomes in K-12 integrated STEM education.

professional development approach since typical training-based professional development's learning outcomes can be lost easily (Liu & Phelps, 2020) and professional development embedded into teachers' work in a way that encourages understanding learners' thinking turns out to be successful (Roth et al., 2011).

In addition to in-service teacher support, our findings also provided insights into the need for an explicit focus on integrated STEM education in pre-service teacher education programs. Specifically, integrated STEM undergraduate courses with both theoretical and practical aspects can be integrated into the existing teacher education programs. This would increase the visibility of integrated STEM education for pre-service teachers and help them collaborate with their peers from other disciplines into which they lack certain insights. In this respect, Guzey et al. (2020) suggested pre-service teacher learning communities in which teacher candidates from different STEM disciplines can work on integrated STEM learning experiences thereby learning from and supporting each other. Such STEM courses can be delivered by teams of faculty from different STEM fields thereby also modeling this kind of interdisciplinary collaborations. Similarly, the researchers also suggested teaching communities of in-service teachers that would lead to achieving successful integrated STEM education through teacher collaboration. This way, both pre-service and in-service teachers from different STEM fields can come together and work collectively to achieve more effective integrated STEM learning outcomes especially in areas that have been incorporated less especially as a main field (i.e., mathematics and technology).

Student characteristics and prior knowledge related to the subject also emerged from our review. As suggested by Pearson (2017), "students' knowledge in individual disciplines should be supported" to make connections across disciplines (p. 225). These insights align with earlier ones related to the role or importance of prior knowledge or ability (e.g., Moehring et al., 2018; Simonsmeier et al., 2018). The role of prior knowledge implies that students' readiness can be an important factor for successful integrated STEM education, and it may be necessary to increase their readiness before immersing them into integrated STEM learning as well as providing continuous student support. In other words, what students bring into an integrated STEM learning experience can impact their learning outcomes thereby mediating any effects of the learning experience itself. Unsurprisingly, then, "optimal STEM learning requires alignment between the teaching and learning context and the students' STEM knowledge and learning capacity" (Nadelson & Seifert, 2017, p. 222). Thus, creating effective integrated STEM learning experiences requires strong conceptual knowledge and teacher scaffolding to foster students' making connections across STEM fields and transfer their knowledge to solve real-life-related engineering challenges (NAE & NRC, 2014). Such efforts are also necessary to promote equity and inclusion efforts in integrated STEM by supporting all students to achieve integrated STEM learning outcomes regardless of their background and prior knowledge in STEM subjects. In addition to providing enough resources and scaffolding to students, teachers can integrate STEM challenges relevant to students' culture thereby making "STEM concepts more socially and culturally relevant" (Moore et al., 2020, p. 5).

In other words, teacher- and student-related factors seem to be related closely in terms of supporting successful STEM integration, which does not seem to be the end of the story: Student knowledge is highly dependent on what students have been learning, which is directly related to the existing curriculum. Therefore, as integrated STEM is considered as an educational innovation, successful integration requires redesigning or modifying the curriculum accordingly (English et al., 2017; Nadelson & Seifert, 2017). Given the importance of a cumulative and interconnected curriculum or content (Hirsch, 2016), integrated STEM may be a meaningful curriculum component that is logically connected to what comes both before it and after it. This way, students can grasp relevant prior knowledge to get the most out of integrated STEM learning experiences. Accordingly, purposeful integrated STEM education supported by teacher-, student-, and curriculum-related factors could provide K-12 students with enhanced learning experiences and outcomes, which would better prepare them for higher grades.

Recommendations for Future Research

One of the limitations of this review is that the factors determined as a result of this review were mainly contextual factors due to the lack of especially true experimental studies looking at cause and effect relationships between factors and outcomes. As a result, there is a need both for further experimental studies focusing on integrated STEM education and for review studies reviewing those experimental studies and providing a comprehensive profile of factors that impact integrated STEM education. In addition, as argued by Honey et al. (2014), "because integrated knowledge structures are developed gradually, it takes time—weeks, months, or years—for researchers to track their growth of student knowledge" (p. 52), future research might also focus on collecting longitudinal data examining the effectiveness of specific instructional strategies on students' conceptual understanding in integrated STEM education. Another area of interest would be how to support both pre-service and in-service teachers for effective implementation of integrated STEM learning experiences in K-12.

Another direction for future research might be conducting systematic reviews focusing on the factors affecting the preparation of teachers who would implement integrated STEM in K-12 education. Such an inclusive research literature would provide us with more informed insights into a more coherent and cumulative approach to successful K-12 integrated STEM education. Lastly, we will need future similar reviews that will timely keep us informed about the characteristics of K-12 integrated STEM education research and the factors affecting student outcomes so that we can achieve informed practice and implementation by integrating up-to-date research insights continuously.

Conclusion

All the factors influencing student outcomes in K-12 integrated STEM research appear to be closely related: For instructional strategies to serve learning outcomes effectively, teacher- and student-related factors are crucial and they all highly depend on curriculum. In other words, just like integrated STEM itself, there is a need for an integrated approach to handling instructional, teacher-related, student-related, and curricular factors to achieve effective K-12 integrated STEM education. The multidimensional nature of factors further implies that effective K-12 integrated STEM education may also depend on a close collaboration of different stakeholders including but not limited to teachers, students, curriculum specialists, and instructional designers. Given the current second dominant state and the connector role of engineering in K-12 integrated STEM education research, it is also crucial to take disciplinary curriculums, STEM teachers' perspectives, and engineering tasks into account to enhance students' learning.

The current results also indicated various instructional strategies or factors that align with active learning with a focus on authentic learning tasks or experiences. Likewise, both teachers' and students' readiness as they relate to especially prior content knowledge appear to be of utmost importance since teachers' scaffolding and collaboration among students turned out to be important dimensions. All these insights refer to the importance of preparing teachers for effective K-12 integrated STEM learning experiences and keeping them updated on that through effective and sustainable professional development. In this regard, both pre-service and in-service teacher preparation policies that encourage sustainable integrated STEM learning can be crucial.

Finally, curriculum-related factors such as quality and extracurricular learning opportunities appear to go hand in hand with instruction-, teacher-, and student-related factors. It appears that quality K-12 integrated STEM education as a component of a larger quality curriculum can be further enhanced through effective instructional strategies as well as higher teacher and student readiness levels. Accordingly, it is reasonable to assume that a long-term and sustainable K-12 integrated STEM education can be better achieved in an integrative manner in which all these instructional, teacher- and student-related, and curricular factors are integrated and complement each other. Such an integrated approach may be necessary during not only the implementation but also the design phase, which can be informed by the engineering design process largely.

Author Bios

Dr. Kadir Kozan is a research associate at Purdue University with a current focus on engineering education and special education as they relate to learning, design and technology. His main research interest focuses on the design, development and evaluation of evidence-informed learning experiences and technology integration. Email: kkozan@purdue.edu

Dr. Secil Caskurlu is an assistant professor at Florida State University and working on large-scale teacher professional development for computational thinking integration in K-12. Dr. Caskurlu's research focuses on designing and developing meaningful learning experiences specifically in online learning environments, systematic reviews, and computational thinking integration in K-12. Email: scaskurlu@fsu.edu

Dr. Siddika Selcen Guzey is an associate professor of science education at Purdue University. Dr. Guzey's research interests include integrated STEM education, biology education, and science teacher preparation. Email: sguzey@purdue.edu

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Appendix

Primary Study Characteristics

Author(s) and year	Integrated fields	Main integrated field(s)	Research method	Data sources	Grade level(s)	Number of participants	Data analysis
Aldemir & Kermani (2017)	S, T, E, & M	S & T	Quantitative	Test of early mathematics ability, science skills checklist, video recordings & photographs, teacher interviews, & document analysis	Pre-K	*62	*t*-test/ANOVA, not specified for qualitative data
Baran et al. (2016)	S, T, E, & M	S, T, E, & M	Qualitative	Activity evaluation forms	6	*40	No description
Baran et al. (2019)	S, T, E, & M	E	Mixed methods	Pre- and post-attitude survey & semi-structured interview	6	*40	Paired sample *t*-test Not specified for qualitative data
Blackley et al. (2018)	S & T	S & T	Qualitative	Scale, observation, open-ended questions, student drawings of their Wiggle Bots	5 & 6	*291	Descriptive for quantitative data, no specific method for qualitative (open coding)
Burrows et al. (2014)	S & E	S	Action research	Pre- and post-test, interview	High school	*56	Descriptive statistics
Burrows et al. (2018)	S, T, E, & M	S & E	Action research	Interview, observation, field notes, focus groups, collected artefacts, & reflective journaling	Middle school	*10	Color coding
Ching et al. (2019)	S, E, & T	E & T	Case study (mixed methods)	Pre- and post-survey, and focus group with students, and semi-structured interview with teachers and teacher reflections	4–6	*18	Paired *t*-test for quantitative data Thematic analysis for qualitative data
Crotty et al. (2017)	S, T, E, & M	S	Quantitative	Teacher logs, pre- & post-content test, observation, & achievement tests	4–9	*2530	Multiple regression
Dare et al. (2017)	S, E, & M	S	Qualitative	Focus group interviews, engineering journal	6	*28	Coding & constant comparison method
Dare et al. (2018)	S, T, E, & M	S	Qualitative	Interview, observation (field notes), digital teaching log	6 & 7	9 middle school science teachers	Content analysis & constant comparison
Dasgupta et al. (2019)	S, T, E, & M	E	Quantitative (exploratory case study)	Process data generated by students' use of the Energy3D software; pre- and post-test	6, 7, & 8	359 (log data) and 318 (pre- and post-test comparison)	Technique described by Vieira and colleagues (Vieira, Magana, & Purzer, 2017); paired sample *t*-test, one-way ANCOVA
English (2019)	S, T, E, & M	E	Qualitative	Audio and video recordings of selected groups' interactions in designing and making their shoes, & whole class discussions	3rd to 6th grade	17	Not specified
English et al (2017)	S, T, E, & M	S, T, E, & M	Mixed methods	Interview, observation audio & video recording, the government school students' workbook responses; student products (buildings, activity booklets), written reflections on the students' problem solving progress	6	*136	Both qualitative & basic quantitative (frequency distributions) analyses

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Appendix
(Continued)

Author(s) and year	Integrated fields	Main integrated field(s)	Research method	Data sources	Grade level(s)	Number of participants	Data analysis
Fan & Yu (2017)	S, T, E, & M	E	Quantitative	Interview, observation, mechanical conceptual knowledge test, design project, higher order thinking skills test, & informal observations	High school	*332 (exp. = 171, control = 161)	*t*-test, ANOVA, ANCOVA, correlation analysis
Fan et al. (2018)	S, T, E, & M	S, T, E, & M	Design-based	Mechanical knowledge test, STEM attitude scale, students' learning document & mechanism projects; oral presentation, researcher's notes of classroom observation	10	*103	Descriptive statistics & dependent *t*-tests; ANOVA & ANCOVA
Glancy et al. (2017)	S, E, & M	S	Qualitative	Observation, audio & video recordings of student group work sessions as well as whole class discussion	5		No description/data were coded using grounded theory qualitative techniques
Guzey et al. (2017)	S, T, E, & M	S	Quantitative	Observation, achievement test scores, curriculum evaluation tool	4–8	*4450	*t*-test, single & multi-level regression
Guzey et al. (2016a)	S, T, E, & M	S	Quantitative	Pre- and post-content test, state mandated test scores, teacher log, & observation	7	*242	Multiple regression & *t*-test
Guzey et al. (2016b)	S & E	S	Mixed methods	Scale, teacher interview, classroom observations	6	*62	Wilcoxon signed ranked test for quantitative, no method stated for qualitative but used inductive–deductive approach for coding
Hernandez et al. (2014)	S, T, E, & M	S	Quantitative	Scale	9–12	*275	Factor analysis & *t*-test
Hirsch et al. (2017)	S, E, & T	E	Mixed methods	Scale, pre- & post-content knowledge test, & student engineering logs, presentations, & drawings	5, 6, & 7	*47	Correlation
Hsu et al. (2017)	S, T, & E	T	Quantitative	Scale, a survey including scale/Likert questions, & open-ended questions	10	*32	Kendall's W test & descriptive statistics
Hudson et al. (2015)	S, E, &M	E	Qualitative	Student work samples, photographs, written responses from students, & researcher notes; archival documents; teacher documentation & interview	4	*19 girls, 9 teachers	
Hynes et al. (2016)	STEM + C	Computational thinking	Qualitative	Observation, video-recorded observations	K-2		Content analysis
John et al. (2016)	S, T, E, & M	S, T, E, & M	Quantitative	STEM Semantics Questionnaire, student engagement, capacity, & continuity (ECC) outcome questionnaire	High school	*20	Descriptive statistics

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Appendix
(Continued)

Author(s) and year	Integrated fields	Main integrated field(s)	Research method	Data sources	Grade level(s)	Number of participants	Data analysis
Kopcha et al. (2017)	S, T, E, & M	E & T	Qualitative	Teacher interview & student open-ended questions	5	*263	Not specified but used descriptive coding
Lambert et al. (2018)	S, T, E, & M	S & M	Mixed method	Scale, final interview questionnaire	Year 1: 5–9 Year 2: 7–8	Year 1: *413 Year 2: *176	*t*-test for quantitative
Marks et al. (2021)	S, T, & literacy	S	Mixed methods	Pre- and post-tests, post-program test, student notebook pages, teacher feedback survey with three open-ended questions	Elementary students	*480 and 9 teachers	ANOVA & qualitative content analysis
McFadden & Roehrig (2019)	S & E	S	Qualitative	Observation, field notes, classroom video, teacher lesson plans & student worksheets (including student work), pictures of student actions, & participant conversations during small group activities	4	*4	Discourse analysis
Moreno et al. (2016)	S, T, E, & M	E	Quantitative	Scale, pre- & post-achievement test	1–5	*278	*t*-test, hierarchical multilevel model
Ng & Chan (2019)	M & T	T	Design-based research	Field notes of teaching experiments, videotaping of teaching experiments, students' initial paper designs, screen captures of students' final designs, students' written assignments, & field notes of post-lesson meeting with teachers	Upper primary & lower secondary		Thematic analysis
Ntemngwa & Oliver (2018)	S & T	S & T	Qualitative	Interview, observation	6 & 8	*70	Constant comparison
Ortiz et al. (2017)	S, E, &M	S, E, & M	Mixed methods	Scale, interview	6,7, & 8	*52	Paired *t*-test, Cohen's d & qualitative content analysis
Robinson III et al. (2014)	S, T, E, & M	E	Quantitative	Pre- & post-achievement tests	8	*105	*t*-test
Sarican & Akgunduz (2018)	S, E, & M	S	Quantitative	Scale, academic achievement tests, & permanence test	6	*44	Mann–Whitney U test & *t*-test
Savard & Freiman (2016)	S, T, E, M, + socio-cultural context	M	Qualitative	Scale, interview, observation, end of the project assessment: complex task & video recordings	5, 6, & 7	*45	Not specified
Shahali et al. (2017)	S, T, E, & M	S	Quantitative	Scale	Lower secondary students (13–14 years old)	*242	Content analysis, *t*-test
Shahali et al. (2019)	S, T, E, & M	E	Mixed methods	Survey & interview	Middle school	*121	One-way repeated ANOVA & content analysis
Sheffield et al. (2017)	S, T, & M	Not explicit	Qualitative	Survey, videos & pre-service teachers' observations	5 & 6	*71	Not specified

(continued)

Appendix
(Continued)

Author(s) and year	Integrated fields	Main integrated field(s)	Research method	Data sources	Grade level(s)	Number of participants	Data analysis
Sinatra et al. (2017)	S, T, E, & M	S	Qualitative	Classroom observations, student focus groups, & semi-structured interviews with teachers	4	*28	Not specified
Tank et al. (2015)	S, T, E, & M	E	Qualitative	Observation (video recordings) & student artefacts	4	*23	Deductive coding, content analysis of video recordings, & student artefacts
Toma & Greca (2018)	S, T, E, & M	S	Quantitative (there is also a qualitative component)	Scale, interview, achievement test, attitude scale	4	*55 treatment, *41 control, & 4 teachers	*t*-test conventional content analysis for interviews
Valtorta & Berland (2015)	S, T, E, & M	E	Qualitative	Observation (classroom video recordings)	High school	*31	Discourse analysis
Wan Husin et al. (2016)	S, T, E, & M	S, T, & E	Quantitative	Pre- and post-test (used as questionnaire)	**Second school	*125	Descriptive statistics & *t*-test
Wilhelm et al. (2013)	S, T, E, & M	S	Quantitative	Scale & tests	6	*66 control, *124 experimental, 3 teachers	RMANOVA, ANCOVA
Wolf et al. (2020)	T & E	E	Mixed methods	Field notes, survey	5–12	*84	Not specified
Yaki et al. (2019)	S, T, E, & M	E	Quantitative	Science achievement test	11	*100	ANCOVA
Yoon et al. (2014)	S, T, &E	E	Quantitative	Scale, pre- & post-test, SKT (content knowledge test), EIDS scale (engineering identity development)	2–4	*831 (n = 741 treatment, n = 90 control)	Two-way ANCOVA
Zheng & Sundaram (2011)	S, E, & T	E	Mixed methods	Scale, including open-ended questions	High school	*151	Descriptive statistics for quantitative data, not specified for qualitative data

Note. *Participants are students. **Second school = secondary school.