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REVIEW

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What do integrated STEM projects look like in middle school and high school classrooms? A systematic literature review of empirical studies of iSTEM projects

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Abstract

The past 20 years has seen a growing focus on the integration of Science, Technology, Engineering and Mathematics (iSTEM) disciplines in schools to provide students with authentic experiences in solving real-world problems. A frequently stated aim for iSTEM projects has been increasing engagement and interest in pursuing STEM subjects in senior high school and tertiary studies. In order to better understand the iSTEM projects' landscape in school classes, this systematic literature review analysed empirical studies of integrated STEM projects carried out in secondary schools to answer the following questions: What are the characteristics of the projects described and to what extent do these projects reflect characteristics of effective STEM projects; and to what extent does research into iSTEM projects in classrooms investigate specific methods of integration of STEM domains? Thirty-five peer-reviewed publications were identified from database searches that met the following inclusion criteria: (a) integrating two or more of the STEM areas, (b) middle/high school education and (c) explicitly describing the research intervention. The review revealed a diversity of iSTEM approaches in the literature, with Engineering and Science, particularly Physics, the most commonly integrated fields. Concerns are raised about the degree to which projects are relevant to students and their context and address the diversity found within student cohorts. A gap was found in the literature in detailing how teachers and students enact integration of STEM skills in these projects.

Keywords: Integrated STEM projects, High school, Middle school, Systematic literature review

Introduction

Integration of STEM (Science, Technology, Engineering and Mathematics) fields in projects from K-12 has been proposed as a means of improving engagement with these fields and increasing the selection of related courses at senior high school and university level (Honey et al., 2014). However, despite these efforts, enrolments in STEM fields such as Physics, Engineering, Computing and Mathematics at tertiary level continue to be of concern (Office of the Chief Scientist, 2020).

However, despite the focus over the past 20 years on engaging student interest in STEM fields through providing students opportunities to use skills and knowledge from different STEM domains to solve problems, little is known about the types of projects that are being characterised as integrated STEM projects in the classroom and the ways in which the domains are integrated. When teachers or researchers talk about projects that integrate STEM, are certain STEM domains, such as engineering and science, more likely to be addressed than others? In addition, to what extent and in what ways are data being collected and analysed to explain how STEM domains are being integrated by teachers and students while carrying out projects characterised as integrated STEM projects?

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As a snapshot of the types of projects that integrate STEM, this systematic literature review aims to investigate these questions by analysing empirical studies of projects that claimed to integrate STEM domains, within classroom settings, from 2000 until the end of 2021.

Definitions of integrated STEM

There has been much debate about what constitutes integrated STEM education and hence there has also been disagreement about the most effective ways to approach instruction when integrating STEM domains (Moore et al., 2020; Nadelson & Seifert, 2017; Sgro et al., 2020). STEM integration is frequently defined as the attempt to support students in making connections between two or more of the STEM disciplines within an authentic context (Kelley & Knowles, 2016; Moore et al., 2014). This models real-world experiences where teams of professionals from differing disciplines work together to solve real-world problems. For the purposes of this systematic literature review, we examined STEM projects that involved interdisciplinary or transdisciplinary integration of at least two domains (Honey et al., 2014; Kelley & Knowles, 2016; Li, 2018). Interdisciplinary integration involves relating closely linked concepts and skills from two or more disciplines with the aim of deepening knowledge and skills (Vasquez et al., 2013). Transdisciplinary integration applies knowledge and skills from two or more disciplines to real-world problems and projects to shape the learning experience (Vasquez et al., 2013).

There are differences in the interpretation of the T and the E in STEM at the school level. Some curricula interpret Technology as digital technology, while in other countries, Technology is design and technology. For the purposes of this research, we adopt the Australian conception in which Technology represents both digital technology and design and technology (ACARA, 2022). Few jurisdictions include Engineering as a school subject (apart from the USA), so in the STEM context, this element of the acronym is increasingly considered as a reference to the Engineering design process, as promoted by the Next Generation Science Standards (NGSS, 2022).

Prior reviews of integrated STEM literature

Even though the acronym "STEM" was only coined in 2001, there has been a large amount of literature published on the topic. Trends in STEM literature over the preceding period were analysed by Li et al. (2020) who found that research in STEM education has increased in importance over the two decades since the term was first used, but that there was a lack of consensus about what constitutes STEM and particularly, integrated STEM. The diversity of opinions and definitions of STEM has contributed to difficulties in carrying out general literature reviews to describe the field (Li et al., 2020). As a consequence, many of the literature reviews available focus on narrow areas of integrated STEM education.

For instance, a review of commonly used teaching strategies in integrated STEM education (Mustafa et al., 2016) indicated that project-based learning approaches were most prominent. Likewise, a systematic literature review by Thibaut et al. (2018) investigating the instructional practices employed when implementing integrated STEM projects found that integration of STEM content, problem-centred or problem-based learning, inquiry-based learning, design-based learning and cooperative learning were the most common frameworks used. However, neither of these reviews analysed the ways in which STEM domains were explicitly or implicitly integrated within each of these instructional approaches.

A systematic review looking at the major challenges in implementing integrated STEM projects identified limited teacher confidence, lack of guidance to teachers in planning projects, and knowing how to effectively integrate STEM areas, as the major reasons why teachers avoided carrying out such projects (Arshad et al., 2021). Teachers themselves confirmed that, while they think that carrying out integrated STEM projects is beneficial to students, they frequently encounter challenges in fitting STEM projects into a busy curriculum, have not been provided with pedagogical tools for implementing such projects, lack support through professional development and collaboration opportunities, and hold concerns about whether students will learn the required curriculum content (Margot & Kettler, 2019). However, the characteristics of projects being presented to students as integrating STEM, have not been analysed. Considering the lack of clarity and consensus surrounding definitions of integrated STEM projects amongst researchers, it is not surprising that teachers are unclear and are lacking in confidence about how to proceed.

Consequently, without a clearly defined theoretical framework for integrated STEM education, there has been a lot of debate about what constitutes best practice in the integration of STEM fields. Based on a detailed analysis of literature published about integrated STEM, Roehrig et al. (2021) developed a comprehensive framework to conceptualise good practice when developing integrated STEM projects. They identified seven characteristics of effective STEM projects:

- Making an engineering design process central to the project, during which students participate in at least one cycle of designing, evaluating and re-designing;
- Choice of authentic problems which are relevant to the students' contexts, which take into account the

diversity of students, and address social, political or ethical aspects of the problem or socio-scientific issues (SSI);

- The context of the problem needs to allow for explicit connections with developmentally appropriate subject content, skills and learning goals;
- In addition, explicit connections should be made between the content in targeted disciplines which could involve multidisciplinary, interdisciplinary or transdisciplinary approaches;
- Development of STEM practices are necessary in order to produce solutions, such as active social construction of understanding, collection, analysis, manipulation and visualisation of data, argumentation supported by evidence-based reasoning and consideration of multiple aspects of the problem (e.g., social benefits or costs);
- Employment of twenty-first century skills such as creativity and collaboration;
- Explicit links are made with possible future STEM careers.

In particular, in order to cater for diversity within the classroom, rather than taking a deficit view of what is keeping certain students from engaging with STEM, researchers and teachers are encouraged to think about what can be changed about STEM projects in order to address the interests, skills and experience of all students (Zeidler, 2016). Brotman and Moore (2008) identified important ways in which curricula can become more inclusive, including more gender-inclusive, by: including students' interests and experiences; using real-world problems; engaging with societal problems that are burning issues for students; and encouraging active participation, agency, collaboration and communication. Zeidler (2016) highlights the importance of addressing socio-scientific issues as a sociocultural response to designing inclusive STEM projects. In this review, we adopt Roehrig et al.'s (2021) view of what constitutes effective integrated STEM projects.

Although reviews clarify some of the methodologies and teaching approaches used or recommended for integrating STEM in schools, what is less clear is what types of projects are being put forward as integrated STEM projects, the STEM domains that are most commonly integrated, and an understanding of how integration is achieved. While some jurisdictions provide guidelines for integrating STEM domains (e.g., NGSS Lead States, 2013) the focus of this paper is the enacted curriculum, that is, how guidelines and recommendations for integrated STEM are translated in practice within classrooms (Cal & Thompson, 2014). This systematic literature review seeks to understand these aspects by focusing on empirical studies that describe the integrated STEM projects (the enacted curriculum) being implemented with enough detail to answer the following research questions.

Research questions

Considering middle/high school projects that are identified by the authors as integrated STEM projects:

1. What are the characteristics of the projects described?
    a. What disciplines are explicitly (or implicitly) integrated in these projects?
    b. To what extent do these projects reflect characteristics of effective STEM projects identified by Roehrig et al. (2021)?
2. What are the foci of research in empirical studies of integrated STEM projects? To what extent does research into iSTEM projects in classrooms investigate specific methods of integration of STEM domains?

Methods

In order to systematically review the literature to answer the research questions the following Preferred Items for Systematic Reviews and Meta-Analysis (PRISMA) (Moher et al., 2009) steps were addressed: establishing relevant inclusion/exclusion criteria; determining a search strategy; searching and screening potential studies; evaluating included studies; analysis and synthesis of themes. The inclusion and exclusion criteria utilised were:

Inclusion criteria

- Empirical studies reporting the implementation of an iSTEM project.
- The authors identify two or more disciplines of STE or M addressed. The project may also include STEAM (with the Arts) or STEMM (with Medicine) dimensions.
- The iSTEM project is explicitly described; summarised in the methodology and/or illustrated with excerpts/examples in the results.
- The projects involved middle school (Grades 5–8) or high school students (Grades 9–12) or appropriate equivalents.
- Data may be qualitative and/or quantitative.
- The intervention can take place outside of the school setting—informal settings.

Exclusion criteria

- Study is published earlier than 2000.
- Study describes STEM projects with elementary and university age students.
- Limited description of the project/s being implemented.
- Theoretical papers.
- Review papers.
- Papers not written in English.

Search strategy

Title, abstract and keywords were searched in ProQuest, ERIC, Scopus, Sage Journals and Web of Science databases using a search for terms agreed between the authors, these being: *"integrated STEM"* OR *"integrated STEAM"* OR *"integrated STEMM"* OR *"interdisciplinary STEM (STEAM/STEMM)"* OR *"Science, Technology, Engineering and Mathematics"* AND *"project*"* AND *"secondary school"* OR *"high school"* OR *"middle school".* It was decided to limit the scope of the study to publications from January 2000 onwards, since the term STEM was coined in 2001.

Data screening and extraction

The data screening process is described in Fig. 1. The search results ($N=221$) were imported into an Excel spreadsheet and duplicates and conference proceedings were removed ($n=106$). Each author then independently checked the titles and abstracts of the remaining articles ($n=115$), excluding those studies that did not meet the inclusion criteria ($n=71$). Where conflicts arose, the authors consulted and discussed whether to include or exclude the study.

In the second phase of screening, the authors individually examined the full text of studies ($n=44$) and made decisions to include or exclude the studies based on the inclusion criteria. Where conflicts relating to decisions about exclusion/inclusion occurred, the authors met to resolve them.

Finally, authors extracted data from the remaining 35 studies, including publication date, country of the author and setting of the study, study design, data type collected, type of class (unidisciplinary or multidisciplinary) data was collected in, STEM fields integrated, whether integration is elaborated, a description of the scope of the project(s), instructional approach, cohort and research focus. One other author then checked the extracted data for accuracy. The extracted data were then summarised, and further thematic analysis was carried out where appropriate.

Data analysis

For most of the data extracted, analysis involved aggregating numbers of papers within each category. However, in the areas of domains of STEM integrated, instructional approaches, whether student context/interests are addressed, student autonomy and research foci, themes were identified within each area. For instance, within the research foci, the theme 'development of students' content knowledge' arose as an important focus of research within these articles. In order to determine which domains were integrated within the project, the authors first searched for statements by the authors of the study that specifically identified domains such as Physics or Engineering. In some cases, when domains were not explicitly identified, the authors identified domains from the description of the project and the activities carried out which implied that certain domains were addressed. Data from each paper were placed under each of these themes as appropriate. When new themes arose during this initial analysis, these were added. Once saturation of themes was achieved and no more major themes arose (Bryman, 2012), the authors cross checked each other's analysis of themes.

Results

Research question 1: characteristics of studies

The 35 articles which met the inclusion criteria were published in 25 different journals (see Additional file 1 for a complete list). The majority of these journals had either a Science focus (e.g., *Journal of Research in Science Teaching*) or at least two STEM areas (e.g., *Journal of Science Education & Technology*) (Fig. 2). No articles were found in journals which focused solely on Mathematics.

There were no articles found before 2010, although the number of articles for each year has increased steadily since then (Fig. 3). The research described in the included articles was carried out in 8 different countries, 60% in the USA (Fig. 4). The majority of studies had a case study design or were quasi-experimental using pre/post tests (Fig. 5). In one article, the methodology was unclear. Thirteen studies focused on qualitative data, seven on quantitative data, while 14 collected both qualitative and quantitative data. Data types collected from the studies are described in Table 1 (as many studies utilised multiple data sources, the total number in Table 1 exceeds the sample size of 35). The cohorts who participated in iSTEM projects and who were the focus of the papers ranged from Grade 5 to Grade 12 students and included mixed age groups (Fig. 6). Some of the articles described participation in a range of different STEM projects for several grade levels.

We also examined the types of classes in which the iSTEM projects were carried out. About half of the

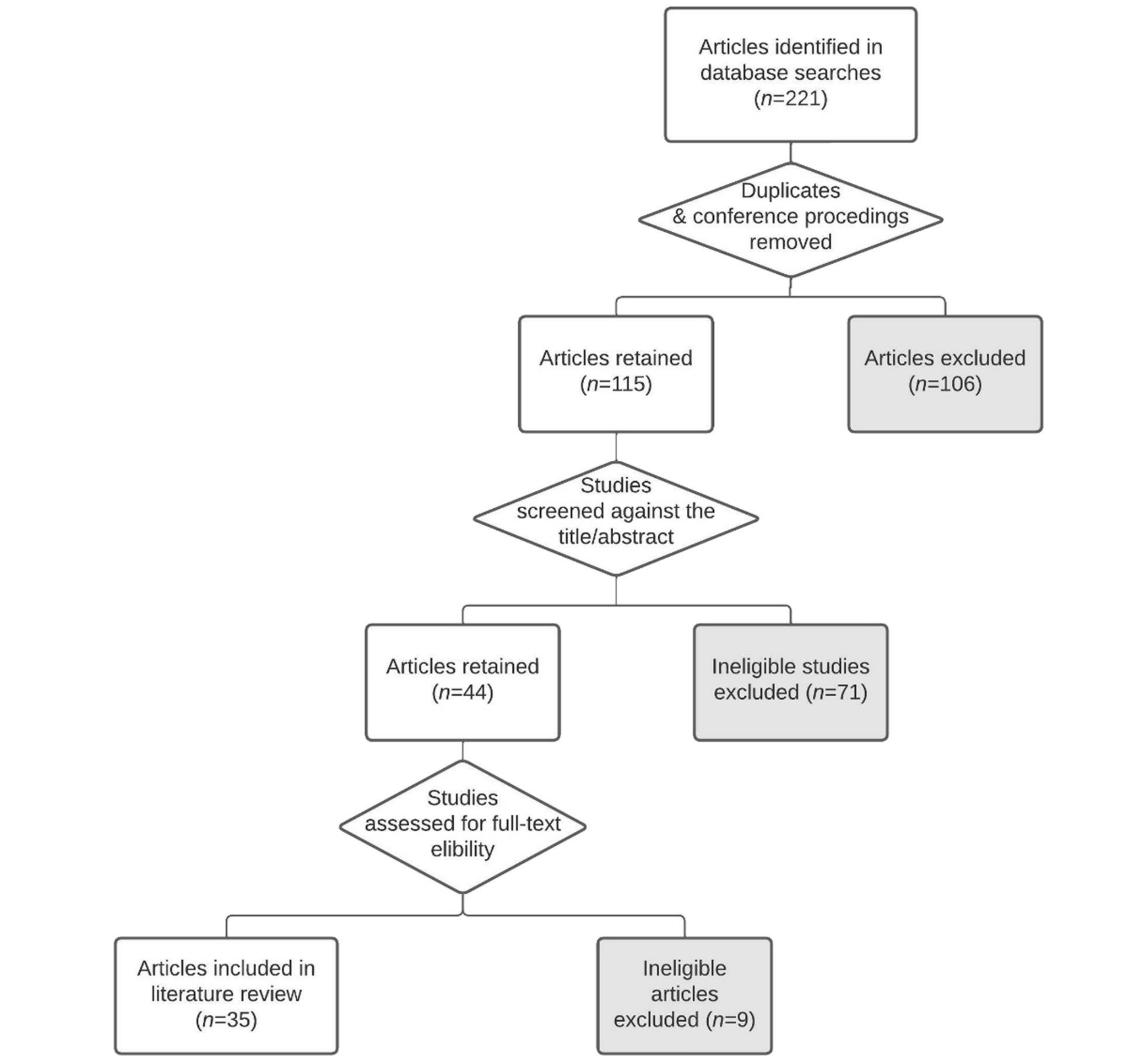

Fig. 1 PRISMA flowchart

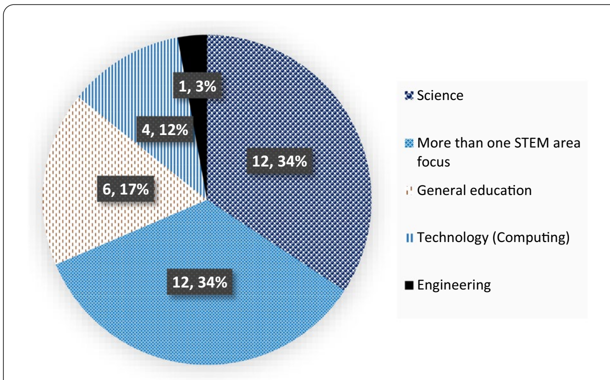

Fig. 2 Subject area focus of publishing journals

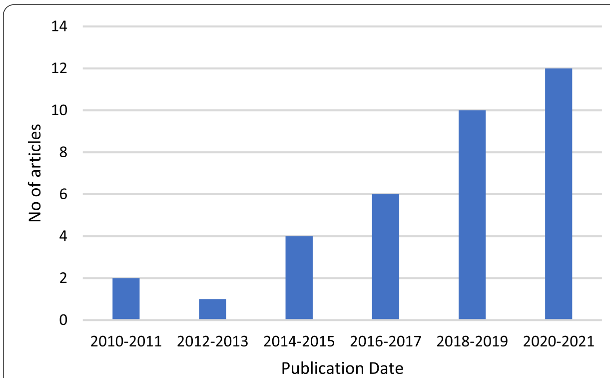

Fig. 3 Publication date of included articles

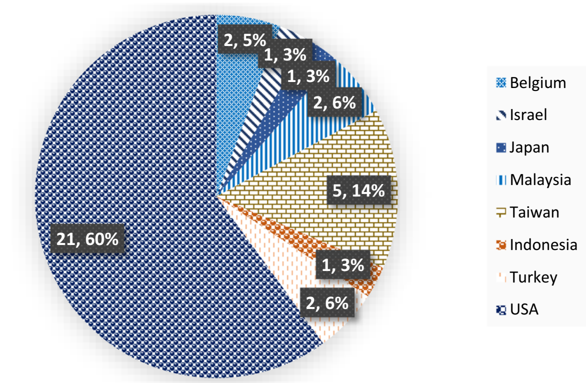

Fig. 4 Countries where research was carried out

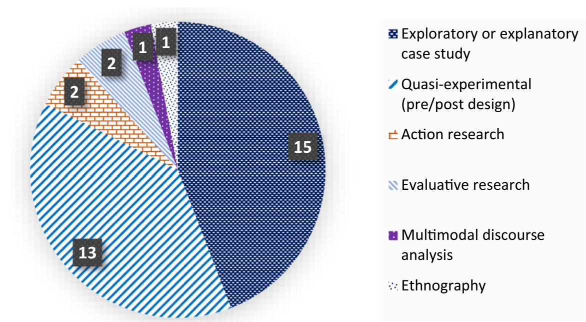

Fig. 5 Reviewed articles study design

Table 1 Data types collected

Data types	No. of studies
Pre/post-test (content knowledge or skills)	17
Questionnaire (perceptions- students)	10
Classroom or Group Observations (journals/field notes)	13
Interviews/ Focus groups (teachers and/or students)	18
Lesson video/audio recordings (transcription)	8
Student artefacts (worksheets, reports, homework, online platform, data logs of design actions)	12
Curricular documents	2
Teaching materials/logs (digital or other)	3
Evaluation by the teacher/s	1

projects were implemented in unidisciplinary classes (i.e. classes that normally focus on one of the STEM subject areas). Of these, 14 were projects implemented as part of Science classes, two as part of Engineering classes and one as part of a Technology class. Eighteen of the studies implemented iSTEM projects in a multidisciplinary class

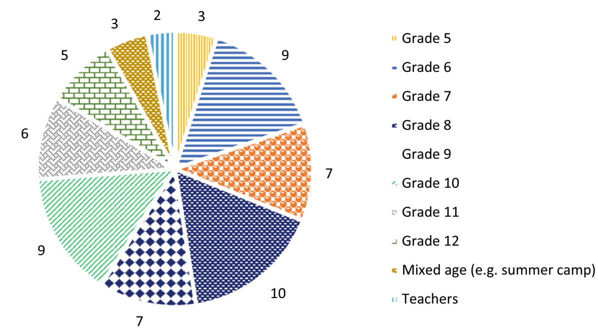

Fig. 6 Cohort described in the reviewed studies

Table 2 Areas integrated in the projects

Areas	No. of studies
STEM	10
Science & Engineering	8
Science, Engineering & Maths	5
Science, Technology & Engineering	3
STEAM or STEM + Social Science + English	3
Science, Technology & Maths	2
Science & Technology	1
Science only	1
Technology & Engineering	1
Engineering only	1

where the focus was specifically on integrating several STEM areas.

What disciplines are explicitly (or implicitly) integrated in these projects?

In response to research question 1a, we firstly examined the STEM areas that were integrated within the project. Twenty-four of the studies elaborated which areas were integrated, while five gave limited descriptions of integration, and integration was not the focus for six studies. Areas of integration are listed in Table 2. Science skills and content knowledge featured in all but two of the studies, while 31 studies included an Engineering focus. Twenty studies explicitly discussed integration of technology (e.g., through robotics, electronics, 3D printing, computer programming). Likewise, 20 of the studies indicated that mathematics was integrated into the project. Although all the studies claimed to be integrating a number of STEM areas, two studies only focused on one area (Table 2).

Within the Science domain, content knowledge from Physics, Chemistry, Biology and/or Earth Science (including Astronomy) was identified as a focus of the

Table 3 Science learning areas addressed in projects

Learning area	No. of studies
Physics	21
Biology	11
Chemistry	8
Earth/space	4
Science Inquiry Skills	1

Table 4 Types of projects described

Project types	No. of studies
Design challenges resulting in building a prototype	23
Hands-on learning activities	11
Student-designed inquiry projects	3
Abstract problem solving	2

project (Table 3). Physics topics were the most commonly included Science topics in STEM projects. Note that some projects included more than one Science learning area.

To what extent do these projects reflect characteristics of effective STEM projects identified by Roehrig et al. (2021)*?*

Firstly, we examined whether the engineering design process was central to projects. A wide variety of projects were described. These could be organised under four broad themes described in Table 4: (i) design challenges which involved constructing prototypes (23 studies); (ii) hands-on learning activities (11 studies), such as making DNA models to understand genetically modified organisms (Wanoho et al., 2021); (iii) student-designed inquiry projects (3 studies), such as experiments aimed at explaining metal purification methods (Daman Huri & Karpudewan, 2019); and (iv) abstract problem solving (2 studies), such as brainstorming to solve problems related to space travel (Moreno et al., 2016). There were several articles that described more than one project, such as a study which looked at the integration of mathematics into a number of different STEM projects, including designing and making ballistic devices and understanding the properties of circles and theorems (Nathan et al., 2017). The 23 design challenges met the criteria for an engineering design process as they included at least one cycle of designing, evaluation and re-designing. However, the hands-on learning activities, where the teachers guided students through activities, gave limited opportunities for them to engage with an engineering design process.

In addition to examining the types of projects described, the instructional approaches identified by the authors in each paper could be categorised according to five key principles identified by Thibaut et al. (2018): integration of STEM content, problem-centred learning, inquiry-based learning, engineering design-based learning and cooperative learning. Instructional approaches are summarised in Table 5. Some articles identified more than one instructional approach. The most common approach was an engineering design approach followed by problem-based/oriented learning. Both of these approaches were often combined with inquiry approaches and included cooperative learning. Engineering design was also incorporated into some of the problem-based learning approaches. However, two of the studies focused on presenting learning through a series of guided tasks, such as a NASA unit, "Thinking Like an Astronaut" (Moreno et al., 2016) rather than utilising an engineering design process. Additionally, the focus of one study was on preparing students for assessment. Five studies also specifically referenced a focus on Social Scientific Issues (SSI) (e.g., Wanoho et al., 2021). All of the studies claimed to integrate STEM content. However, six of the articles examined did not identify the instructional approach that they used.

Secondly, we examined each of the articles to understand whether the authors explicitly took into account the students' context or interests in order to produce authentic problems. Of the design challenges, 12 consisted of a design brief which considered the students' context, although student context or authenticity of the projects was not the main focus of these papers, and was often only mentioned in passing. The example which most clearly addressed the students' context was one in which they designed an amphitheatre, within a budget, to meet the needs of the local community (Newman et al., 2015). The other design briefs focused on designing "things" without any explicit relationship to the students' context (c.f., Gunckel & Tolbert, 2018) (e.g., a CO_2 powered model drag racer (Chien, 2017) or designing and building a balsa wood house to survive in a wind tunnel (Barrett et al., 2014)).

Of the projects that focused on teaching a concept or concepts through hands-on activities, none of these considered the context of the students explicitly, although two projects addressed SSIs. Of the projects which focused on inquiry learning, two were context specific. However, students were given agency in designing experiments. Neither of the abstract problem-solving projects specifically engaged with student context.

One way of ensuring that projects are relevant to students is allowing for student design or choice of project topic. Fifteen of the 35 studies implemented projects

Table 5 Instructional approaches

Instructional approach	No. of studies
Engineering design approaches	
Engineering design process	6
Based on Moore et al. (2014)—motivating context/engineering design challenge/redesign/include maths and science content/ student-centred pedagogies/teamwork & communication	3
NGSS Engineering Thinking	2
Engineering Maker-based Inquiry	1
Focus on problems (PBL/POPBL/PCL)	
Project-Based Learning	4
Project Oriented Problem Based Learning (POPBL)	1
Problem Based Learning and Contextualised design challenge	1
Problem centred and Cooperative learning	1
PBL/STEM integration/Inquiry and design-based learning/cooperative learning/ inputs from discipline specific pedagogical research	1
PBL + Inquiry based learning + Engineering design + SSI	1
PBL + Inquiry based learning + Service Learning	1
Cooperative Learning	
Copying examples—discussing redesign-collaboration to make improvements	
Action research project (group negotiated and designed)	1
Hands-on learning	
Task-centred teaching (e.g., a NASA based curriculum)	2
Assessment focus	
Teach, problem solving activity, test	1
STEAM model (scaffolding, tutoring, engaging, argumentation, modelling)	1
STEM-6E model (engage, explore, explain, engineer, enrich, evaluate) including SSI	1
Not specified	6

that were externally designed, either by the researchers or by other experts such as NASA or Curriculum developers (e.g., Petrosino et al., 2016; Wilhelm et al., 2013). A further seven studies described teacher/researcher collaborative efforts to design the STEM project/s (e.g., De Meester et al., 2020). Teachers were instrumental in designing 11 of the projects (e.g., Wieselmann et al., 2021). Only two of the 35 studies gave students agency in choosing the problem to be studied (Kapon et al., 2021; Newman et al., 2015).

Of the 35 studies examined, only three mentioned that they made explicit links for students with possible future STEM careers as part of the project design. For instance, in the project described by Burrows et al. (2014), career connections were explicitly discussed in class and included in assessment questions. However, 18 studies did mention that one of the goals for introducing integrated STEM projects to students is that participation in these may increase engagement with future STEM careers and two of these studies examined whether students had changed their perspective about STEM careers as a result of doing these projects. However, neither of these papers mentioned whether this was an aspect that was explicitly addressed in lessons. In one study, including a "STEM Career Connections" component was considered, but the project designers chose not to because they did not think this was critical to the success of the project (Gale et al., 2020). The rest of the articles did not mention STEM careers at all.

Research question 2: foci of research

In response to research question 2 (What are the foci of research in empirical studies of integrated STEM projects? To what extent does research into iSTEM projects in classrooms investigate specific methods of integration of STEM domains?), the research questions for each study and the outcomes reported were examined. The research themes that were identified are displayed in Table 6. It should be noted that some studies had multiple research foci.

It can be seen from the research foci presented in Table 6 that there is a very limited focus in the literature on describing the ways in which the STEM domains are practically integrated as iSTEM projects are enacted. The largest group of studies focused on the degree to which students had developed STEM-related content

Table 6 Research themes

Research themes	No. of studies
Development of STEM-related content knowledge	12
Development of STEM-related skills	10
Students' learning experience (motivation, self-efficacy, engagement + others)	11
Analysis of student participation during the lessons	10
Attitudes towards STEM/Subjects	7
Teacher perceptions	5
Enactment of STEM integration	5
Challenges to the teachers for implementation	3
Fidelity of implementation in terms of iSTEM	2

knowledge or skills as a result of participating in an iSTEM project. Many of these utilised a pre/post-test design, and in some cases compared results with a control/comparison group (e.g., Chen & Chang, 2018). Of the 12 studies which focused on the degree of content knowledge acquisition, 10 indicated that students had improved content knowledge, while two studies showed no significant learning had taken place. Four studies observed students actively applying STEM knowledge and skills to solve problems. Likewise, most studies noted that STEM skills, including twenty-first century skills, such as creativity and collaboration, improved as a result of participation in these projects. However, one study showed no noticeable improvement in skills.

Students' experience of the lessons in terms of their motivation, self-efficacy and engagement was also a prominent theme, mostly evaluated through questionnaires, interviews, journals and video recordings (e.g., Chu et al., 2020). Seven studies observed high levels of engagement and motivation amongst students as they carried out STEM projects. Likewise, students' attitudes towards STEM subjects and intentions to continue in the STEM pipeline were determined through questionnaires (e.g., Lou et al., 2011). Most of the studies examining changes in attitudes towards STEM indicated an improvement as a result of the STEM projects, although one study indicated no improvement had taken place.

The degree and types of participation of students while completing iSTEM projects, including gender differences, were analysed through classroom observations, videos and journal entries (e.g., Gardner & Tillotson, 2020; Wieselmann et al., 2020). For instance, Wieselmann et al. (2020) showed that boys and girls participate differently in STEM activities within small groups—the boys tending to be controlling and competitive and ignoring the girls' contributions.

Teachers' perceptions of the efficacy of the iSTEM intervention based on questionnaire and interview responses was the focus of five studies (e.g., Gardner & Tillotson, 2019). A number of challenges for implementing STEM projects were described by teachers, such as scheduling difficulties, difficulties using technology, and in making links to the curriculum (Stohlmann et al., 2011). Fidelity of implementation of specific iSTEM approaches by teachers was also analysed in two studies (e.g., Petrosino et al., 2016), and three studies considered the challenges that arise when integrating STEM domains (e.g., Stohlmann et al., 2011).

Surprisingly, the research questions in only five studies specifically targeted the enactment of STEM integration within an iSTEM project. For the most part, these studies carried out detailed analyses of audio/video recordings (e.g., multimodal discourse analysis (Nathan et al., 2017)) of groups participating in STEM projects to understand teacher and student choices/actions/discussions. Mathis et al. (2018) presented a case narrative using quantitative content analysis to describe how students chose to use science and mathematics content through different engineering design phases while solving an engineering problem. Burrows et al. (2018) focused on engineering skills and identified numerous ways in which science, and to a lesser extent mathematics, was integrated while enacting these skills in an informal, community-based project. On the other hand, Dare et al. (2018) focused on iSTEM projects within the Science classroom. Teachers identified the time spent addressing the domains of STEM in each lesson. Teachers were then categorised as having low, moderate or high levels of STEM integration within their classes. They found that teachers are not always aware of how to meaningfully make explicit connections between domains, struggling to integrate mathematics and engineering into science instruction. In particular, engineering appeared to be an add-on, especially for those who had low levels of integration. Wieselmann et al. (2020), on the other hand, found that girls and boys, working in small groups, engaged with science or engineering focused lessons in different ways and may need practice and support in moving between these two discipline areas. In order to promote STEM integration, Nathan et al. (2017) found that cohesion between fields is best achieved when students themselves find their own ways to integrate fields as they apply ideas to more abstract principles.

Discussion

This systematic literature review focuses on two areas that have not previously been investigated: what are the characteristics of projects being classified by researchers/teachers as integrated STEM projects; and to what extent are the specific ways in which integration of STEM domains investigated in the classrooms where they are enacted? In order to take a snapshot of the integrated STEM project landscape, we limited the review to empirical studies of iSTEM projects carried out with middle/high school students.

The authors of the 35 articles which met the inclusion criteria for this literature review identified a wide variety of projects that they considered exemplified integrated STEM. Making the engineering design process central to effective iSTEM projects is one of the recommendations made by Roehrig et al. (2021). Although engineering design was prominent amongst the instructional approaches identified by authors, other instructional approaches were also prominent, such as project based/oriented learning (Table 5). This is consistent with the findings of Mustafa et al. (2016) and Thibaut et al. (2018). However, several projects made no mention of engineering design, focusing on inquiry approaches or hands-on learning. In particular, the projects which presented hands-on learning activities left little or no room for design/re-design by students.

In terms of the types of projects students were engaging with, the authors identified four types (Table 4). Consistent with the engineering design approach used in many of the projects, 23 of the 35 studies gave students a design brief which allowed students to design some kind of physical model or prototype in order to solve a specific problem. These clearly fit the recommendations of Roehrig et al. (2021). However, although 23 of the projects identified by the authors as iSTEM did have an engineering design focus, surprisingly, 16 of the projects described did not specifically use the engineering design cycle. For instance, there were 11 projects which focused on teacher directed, hands-on activities to communicate content knowledge and skills to support students' learning (Table 4) rather than employing the engineering design cycle to address a specific problem. Although these projects allowed students to construct models, for instance 2D and 3D models to explain lunar periodicity and phases (Wilhelm et al., 2013) or DNA models to understand genetically modified organisms (Wanoho et al., 2021), the engineering design process was not followed as students were given limited agency in the design process. This raises the question of whether these fit into the category of integrated STEM projects, especially if the characteristics of effective STEM projects identified by Roehrig et al. (2021) are considered. These findings indicate that researchers (and teachers) may not be operating under coherent definitions of what constitutes an integrated STEM project. We would argue, together with Roehrig et al. (2021), that projects that do not allow students to design their own solutions to problems, evaluate those designs and then re-design do not meet criteria for best practice in integrating STEM domains.

Another feature of effective iSTEM projects is that they enable students to engage with authentic problems which are relevant to their context. On the whole, the engineering design challenges (Table 4) gave students agency in the design/re-design process and the inquiry tasks also allowed students to design experiments. However, considering the recommendations of Roehrig et al. (2021) that effective iSTEM projects should be relevant to the students' context, relate to their interests, and take into account diversity amongst students, it is concerning that only 11 of the studies specifically mentioned that problems relevant to the students' contexts or interests were considered when designing the iSTEM project. For instance, one of the projects, that included a service-learning component, asked students to design an amphitheatre for a local park that the community and school could share (Newman et al., 2015). In addition, five projects explicitly consider socio-scientific issues, such as producing genetically modified organisms, in the project design (Wanoho et al., 2021). These projects may meet the criteria for projects that are authentic and relevant to students of Roehrig et al. (2021). However, it was unclear whether the SSIs addressed were of particular importance to the students carrying out the tasks. This begs the question about the extent to which students' interests and concerns are being considered as iSTEM projects are designed.

In addition, 19 of the projects asked students to design and build artefacts that did not explicitly consider the student context, although these studies stressed the importance of providing real-world problems, that professionals may engage with, to increase student engagement. For instance, a competition to build a robotic arm was thought to be motivating for students, but no mention was made about how this device was relevant to students' lives (Chu et al., 2020). It may not be sufficient to simply provide design problems that represent the types of problem-solving experiences that occur in industry but, as indicated by Brotman and Moore (2008), projects should address issues and concerns that are important to students in order to engage their interest.

This problem is compounded by the fact that, in almost all the studies, students were not given choice about the project that they would investigate. This limits the ability for the iSTEM experience to address diversity of interests and life experiences within the student cohort.

The two exceptions, where students were given choice, were a study in which the students developed the problem that they would investigate: understanding the difference in efficiency between a stationary and tracking solar panel (Kapon et al., 2021); and a service project where students identified problems within their communities to be solved (Newman et al., 2015).

In addition to our concerns over some of the instructional designs of projects being put forward as integrated STEM projects, the degree of integration within projects was not always evident. All of the studies claimed that STEM fields were being integrated within these projects (c.f., Thibaut et al., 2018). However, for some of these studies, integration of STEM was either not the focus or the ways in which these fields were integrated was not evident. When considering the degree of integration of Science, Technology, Engineering and Mathematics within each of the iSTEM projects in this study, it was evident that the Science and Engineering fields dominate within these projects (Table 2). This is consistent with Bybee's (2010) description of the variety of definitions of STEM integration, ranging from Science and Engineering to all four domains. Thirteen of the 35 studies included at least all four domains. In addition, two studies included Social Science and English together with STEM. While 31 studies included the Engineering domain, the majority of these utilised an Engineering Design process rather than the development of engineering content knowledge. All but two of the studies included Science skills or knowledge, and technology was less likely to be identified as a domain that was integrated into the project (20 studies). This is consistent with studies which show that, even though digital technologies are frequently used in projects, the use of these technologies is often assumed rather than explicitly examined (Ellis et al., 2020). Mathematics was also not explicitly included in 15 of the 35 studies. It is possible that in other studies, even though connections with mathematics and technology are not explicitly addressed, they may be seen as tools of science or engineering (Baldinger et al., 2021).

The predominance of physics (21 studies) and astronomy (4 studies) as the Science content area addressed (Table 3) may be related to the number of design briefs that asked students to build prototypes. When limited connections are made between STEM projects and the students' context and interests, and the value to students and the communities that they live in are not made explicit, and when many of these projects have a physics and engineering focus, stereotypes of these subjects may be further consolidated in students' perceptions. Chemistry topics (8 studies), while less common, tended to be associated with inquiry tasks, such as designing experiments to understand the processes involved in mineral purification (Daman Huri & Karpudewan, 2019) or problem solving, for instance to stop corrosion on a metal bridge (Yüceler et al., 2020).

The inclusion of biology topics (11 studies) was also less common than for physics and were sometimes associated with teaching activities to understand biological concepts, such as body systems (Ntemngwa & Oliver, 2018) or design challenges based on biological examples (Gale et al., 2020). However, several of the projects that included biology identified SSIs in the local community, for which students designed solutions through an engineering design process (e.g., Newman et al., 2015). These projects met many of the characteristics of effective STEM projects identified by Roehrig et al. (2021). It may be that incorporating a biology topic into an engineering design cycle appropriate for middle and high school is more challenging to designers than inclusion of physics concepts.

Considering that one of the rationales for introducing iSTEM projects in middle/high school has been to increase students' understanding of what careers in STEM entail, and hence increase students' willingness to consider STEM careers in the future (Honey et al., 2014) our finding that almost no studies explicitly made connections between the iSTEM projects and possible careers, as suggested by Roehrig et al. (2021), is surprising. This may have been due to the research focus of the paper being unrelated to career choice. However, even in the cases where one of the research questions was to understand the influence of participation in iSTEM projects on students' future choice of careers, no mention was made of how students' were informed about connections between their learning in the project and possible careers.

Finally, in response to research question two, the main focus of research involving integrated STEM projects has been on learning outcomes, the degree to which students are learning specific STEM skills and content knowledge as a result of these projects (Table 6). In addition, affective aspects including change in attitudes to STEM, motivation and engagement throughout the STEM project were major foci of research. On the other hand, there were only five studies of exactly how students and teachers enact the integration of STEM domains throughout the project. The focus on learning outcomes related to iSTEM projects may be in an attempt to address the concerns raised by teachers about whether participation in STEM projects is in fact resulting in students learning the required curriculum content (Margot & Kettler, 2019). Likewise, iSTEM projects have been promoted as a way forward for increasing students engagement with and interest in pursuing STEM subjects later in school and at university (Honey et al., 2014), which may explain the number of studies which focus on increasing these affective aspects of learning.

The small number of studies which analyse the enactment of integrated STEM projects, however, is more surprising, particularly when teachers have indicated that they need more direction and support on how to effectively integrate learning areas (Arshad et al., 2021; Margot & Kettler, 2019). In addition, Roehrig et al. (2021) identify that making explicit connections between the content of the targeted disciplines is one of the essential factors for effective iSTEM projects. Of the five studies that investigated the enactment of integration, Burrows et al. (2018), Mathis et al. (2018) and Nathan et al. (2017) were the only studies which specifically addressed the ways in which domains were integrated. Burrows et al. (2018) briefly described how science content was integrated within engineering skills. Nathan et al. (2017), on the other hand, did not focus on integration of all domains but analysed the ways in which the teacher guided engagement with mathematics as students completed mechanical and electrical engineering design projects. Mathis et al. (2018) took the approach of focusing on each of the engineering design phases within an iSTEM project and analysing how students chose to use science and mathematics in each phase while solving the engineering challenge.

On the other hand, Dare et al. (2018) developed an innovative method for measuring the degree of integration within a series of lessons within a Science classroom by using a digital teaching log to identify the length of time spent addressing each domain in each lesson. This allowed the authors to identify teachers who had low, medium and high levels of integration. However, the study did not analyse how individual domains were integrated. Likewise, the study of Wieselmann et al. (2020) looked at frequency of certain performances, such as reasoning, encouraging and suggesting, within lessons that they identified as focusing on either Science or Engineering, rather than on how Science and Engineering were integrated. What is clear is that it is challenging to find ways in which to measure the degree of integration of domains and describe ways in which they are integrated. This finding suggests that there is much scope for classroom-based studies to probe effective strategies for integrating STEM domains.

Limitations and recommendations

It is possible that by including some of the search terms, such as projects, into the search engine criteria some integrated STEM studies may have been missed. The search also only included studies in English, which, perforce, limits the number of studies.

However, we offer the following recommendations for further research based on the scope of the studies that have been included. Firstly, further research is needed into the types of projects that would engage a greater diversity of students. For instance, a focus on designing "things" (Gunckel & Tolbert, 2018), untethered to students' interests or concerns, may be one of the reasons why girls, in particular, are less motivated than boys to participate in integrated STEM projects (Brotman & Moore, 2008; Koul et al., 2021). Students' beliefs that STEM careers do not address their diverse interests and concerns, including gendered interests, has been identified as one of the reasons that females are not choosing to continue to study subjects such as engineering, physics and computer science (Su et al., 2009). The higher enrolment of females in biology and, to a lesser extent, chemistry in preparation for caring careers, such as in the health sector, is indicative of gendered interests that are, on the whole, not being addressed within the context of iSTEM projects (Eccles & Wang, 2016). This is highlighted by the preponderance of physics-based projects presented in these studies (Table 3). Projects which only set one type of problem, such as building a ballistic device (Nathan et al., 2017) or CO2-powered model drag racers (Chien, 2017) may be of interest to some students, but do not take into account the diversity of students (Roehrig et al., 2021), and may, in fact, perpetuate stereotypical perceptions of engineering as the preserve of males (Master et al., 2016). We would suggest that, in order to address diverse interests within the student cohort, further research is needed into whether targeting biology within the Science domain of iSTEM projects increases the engagement and interest of girls in STEM.

Secondly, further research is needed regarding the effects of giving students more agency in choosing the problem that will be addressed through the STEM project.

Thirdly, the effects on attitudes towards STEM careers of making explicit links with possible careers as students carry out STEM projects is another area of research suggested by the results of this literature review.

Finally, the limited number of studies which investigate specific ways in which STEM domains are integrated suggests that further research is needed into methodologies for measuring the degree of integration and understanding best practice to effectively integrate STEM domains.

Conclusion

This systematic literature review addresses two main research questions: What are the characteristics of the projects described and to what extent do these projects reflect characteristics of effective STEM projects identified by Roehrig et al. (2021); and to what extent does research into iSTEM projects in classrooms investigate specific methods of integration of STEM domains?

It was evident that there were a wide variety of ways in which researchers and teachers understand STEM integration. While a majority of studies claimed to integrate, at least, Engineering and/or Science, only half of the studies presented students with an engineering design challenge which asked students to apply the engineering design cycle, as recommended by Roehrig et al. (2021). Mathematics and technology were less likely to be explicitly addressed within these projects. The specific ways in which integration of STEM domains occurred was only discussed in a small number of papers. The majority of studies focused on the effects of iSTEM projects on content and skill acquisition or on attitudes towards STEM. Only five studies examined the enactment of STEM integration within the classroom, and of these, only three explicitly examined processes for integrating domains, leaving much scope for further investigations in this area. This suggests that there is an extensive gap in our understanding of the practical ways in which STEM integration occurs and is made explicit to students (Roehrig et al., 2021). Another recommendation of Roehrig et al. (2021) was that projects should be relevant to students interests and context. Only 11 studies explicitly took into account the context of the students or their interests, and of these, some made assumptions about what the students may be interested in. Additionally, only two studies gave students choice in determining the engineering design question. This lack of student agency and relevance may provide a further barrier for engaging with iSTEM for some students. Further research is required to understand the importance of student agency in designing iSTEM projects and in finding ways to more authentically address student context and interest. In addition, a major rationale for introducing iSTEM projects into schools has been to raise student awareness of careers in STEM. The limited number of studies that explicitly made connections between the projects described and possible STEM careers, suggests that this is another area for further study.

Abbreviations
iSTEM: Integrated Science, Technology, Engineering and Mathematics; PBL: Project based learning; PCL: Project centred learning; POPBL: Problem oriented project based learning; SSI: Socio-scientific issues; STEMM: Science, Technology, Engineering, Mathematics and Medicine; STEAM: Science, Technology Engineering, the Arts and Mathematics.

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Additional file 1. Complete list of included articles.

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Author contributions
FM carried out the initial literature searches, completed the title/abstract and full-text screening, analysed the extracted data for themes and wrote initial drafts of the paper. KT also carried out title/abstract and full-text screening, analysis for themes and provided content and editorial advice on the final paper. PW also performed title/abstract and full-text screening, analysis for themes and provided content and editorial advice. All authors read and approved the final manuscript.

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Declarations

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