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STEM in the classroom: a scoping review of emerging research on the integration of STEM education within Australian schools

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Abstract
The paper presents a scoping review of research that has been conducted on integrated STEM programmes in Australian schools over a 10-year period (2012–2022). It aims to determine how integrated STEM is being practiced. A total of 17 papers were chosen for review. The review explored the major characteristics of research that has been conducted on integrated STEM programmes in Australian schools, the teaching strategies used to teach integrated STEM and the reported impacts of these programmes. In fifteen of the papers experts from outside the school such as scientists and engineers, usually academics, were involved. Cooperative learning, project/problem-based learning and authentic experiences were the most common teaching strategies in a field characterised by positive learner outcomes. It is evident that teaching strategies are significant in the integration of STEM. Future research should focus on addressing issues of ecological validity, sustainability and scalability to ensure as many students as possible reap the benefits of high-quality STEM education.

Keywords STEM education · Schools · Curriculum · Pedagogy · Integrated learning

Introduction

STEM education is characterised by the integration of science, technology, engineering and mathematics disciplines in order to emphasise problem-solving and critical thinking in ways that are meaningful and authentic for learners (Education Council, 2015; Gee & Wong, 2012; Rosicka, 2016). Globally, STEM education is viewed as critical to economic and social prosperity due to its contribution to innovation and sustainability (ACARA, 2016; Bybee, 2013). Parallel to the economic

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importance placed on STEM education are calls for STEM education to be more responsive to global and national ecological and biological crises (Gough, 2021; Kelley & Knowles, 2016). In the Australian context, international, standardised mathematics and science testing regimes have reported mixed results in Australian students' academic performance, as well as declining interest in STEM-related occupations (Education Council, 2015; Georgiou, 2023; Thomson et al., 2020). This has led to some apprehension about Australia's capacity to realise its potential in an increasingly complex and future-driven world. This apprehension is captured in calls to prioritise and improve Australian STEM education (Australian Office of the Chief Scientist, 2014).

Pivotal to the reform of Australian STEM education is a National STEM School Education Strategy 2016–2026 (Education Council, 2015). The strategy represents an agreement among Australian education ministers to improve STEM education through collaborative approaches, underpinned by an agreed framework for STEM education, at a national level. A key pillar of the strategy is implementation through a cross-disciplinary, integrated approach to teaching the key learning areas of Science, Technology, and Mathematics. This approach is premised on the evidence that an integrated approach, that connects discipline areas, promotes stronger student engagement in STEM (Hunter, 2020; Redman, 2017; Struyf et al., 2019). A further central element of the strategy is that collaboration among teachers and STEM professionals can enhance STEM education delivery and outcomes (Education Council, 2015, 2018). However, both the conceptualisation and enactment of STEM education in school settings can be hindered by issues of inconsistency and opacity in policy (Roehrig et al., 2021; Sgro et al., 2020).

STEM education in the Australian context has been left to schools to develop and tends to be delivered in separate discipline areas (Anderson, 2020; Falloon et al., 2021). In some ways, this is a function of the siloing of STEM disciplines in the Australian Curriculum (ACARA, 2021). Each Australian state and territory is responsible for adapting, enacting and monitoring the implementation of the Australian Curriculum, with public, independent and catholic schools having considerable discretion in how STEM is taught. The cascading responsibilities in the Australian education system add further complexity to STEM education. To account for the varied stakeholders and contexts, Australian STEM education strategies tend to be rather broad (Murphy et al., 2019). The unique complexity of the Australian education system may, to some degree, explain the disjuncture between STEM policy emphasis and mixed student outcomes (Sheffield et al., 2018). Indeed, while Australian year 8 student's science performance in the OECD's Programme for International Student Assessment (PISA) has declined, Trends in International Mathematics and Science Study (TIMSS) data have signalled recent improvement in Australian students' science outcomes (Georgiou, 2023). There has been some movement toward embedding more STEM integrated approaches within schools, including implementation of STEM approaches in primary school (Anderson et al., 2019; English, 2016a, 2016b). Schools may do this through one off STEM days where they bring STEM experts in to deliver activities, STEM interest programmes or clubs for students during lunchtime or after school while some schools have implemented a standalone STEM subject (Davis et al., 2023).

STEM education has tended to emphasise student agency through teaching approaches such as project-based learning, problem-based learning, and extended inquiry (Murphy et al., 2019; Newhouse, 2017; Pressick-Kilborn et al., 2021). Such broad teaching strategies assist students in their skills development and higher order thinking and application and can be effectively contextualised through community engagement (Chiu et al., 2023), focused classroom integration (Jacobs, 2022), and supplementary STEM clubs (Davis et al., 2023). According to Sanders (2012) integrated STEM must be inclusive in scope, emphasise higher order thinking in authentic contexts, and focus on knowledge, skills, and dispositional outcomes holistically. Furthermore, each discreet STEM discipline integrated into a broader STEM learning experience must be required to fully achieve the outcomes of the experience. In practice, STEM experiences are taught through complex repertoires of specific approaches, such as direct instruction (e.g. Godino et al., 2016) and modelling (e.g. Ozogul et al., 2019) nested within broader pedagogies/ principles, such as Higher Order Thinking (e.g. Chin, 2007) and Authenticity (Martin et al., 2016). A selection of key STEM teaching approaches considered in this paper is presented in Appendix 1.

Honey et al. (2014) proposed that STEM integration involved 'working in the context of complex phenomena or situations on tasks that require students to use knowledge and skills from multiple disciplines' (p. 52). In proposing a framework for STEM literacy development Falloon et al. (2021) stated that the literature displayed variation in its interpretation of, and rationale for, STEM education, and how it should be taught and assessed in schools. Anderson (2020) in considering the varied approaches to STEM in Australia notes that there is a particular reluctance on the part of mathematics and science teachers to go beyond their disciplines and maintains that:

> The challenge remains to encourage STEM teachers to embrace problem solving and inquiry-based learning and to consider ways to support teachers in linking knowledge both within their discipline as well as between disciplines through curriculum integration. (p. 220)

The development of authentic problems requiring knowledge from all the STEM subjects is not straightforward and presents a challenge for teachers with the structure, content and pedagogical practices of an integrated STEM curriculum not well understood (Anderson, 2020). Furthermore, many teachers do not necessarily possess specialist training in specific STEM disciplines. They may have received generalist training in their teacher education degree or they might be called upon to teach discipline areas that they have no specialist training in (Millar, 2020).

To provide the additional clarity needed to translate STEM policy into classroom practice consistently, this paper presents a scoping review of research that has been conducted on integrated STEM programmes in Australian schools over a 10-year period (2012–2022). It aims to identify the key characteristics of the research on integrated STEM in Australian primary and secondary schools, report on the teaching strategies used to teach integrated STEM and looks at the reported impact of integrated STEM programmes. The following research questions are explored in this scoping review:

Research Question One (RQ1)—What are the major characteristics of research that has been conducted on integrated STEM programmes in Australian schools over a 10-year period (2012–2022)?

Research Question Two (RQ2)—What teaching strategies are used to teach integrated STEM in Australian schools?

Research Question Three (RQ3)—What is the reported impact of these programmes?

Method

A scoping review methodology (Peters et al., 2020) was selected for the current study, as the approach aligns with the aim of considering emerging research on the integration of STEM education within Australian schools.

The aim of the review was to determine the range and nature of research activity and to summarise and disseminate research findings (Arksey & O'Malley, 2005). Eligible studies met the inclusion criteria if; (i) the paper considered STEM integration, (ii) the school was in Australia, (iii) the project was classroom/student based, (iv) study was in a primary or secondary school. Studies were excluded for the following reasons; (i) Preschool focused, (ii) conceptual, (iii) not classroom based. Editorials, protocols, commentaries, theses and reviews (narrative, scoping and systematic) were excluded from reviewing.

Search strategy

Between 11 and 12 May 2022, the databases of ProQuest Education, EBSCO (Education incorporating Education Resource Information Centre (ERIC)) and SCOPUS, were searched for papers pertaining to empirical research on STEM integration in the classroom. These databases were selected as they captured the majority of key journals publishing research on all levels of school education and STEM. The search strategy was kept simple to include 'pedagogy' and/or 'curriculum' and 'integrated learning' related to STEM in the school classroom in the abstract. Table 1 provides the boolean strings employed in this literature search. The search was limited to a focus on Australian studies with a 10-year limit applied. This search yielded a total

Table 1 Boolean search string terms

Boolean search string 1:	STEM education AND curriculum STEM education AND pedagogy
Boolean search string 2:	STEM education AND integrated learning

Two researchers went through the abstracts to determine their relevance—school context, considering integrated STEM, and practice or theory focus. Qualitative, quantitative and mixed methods peer-reviewed studies were included of 173 papers across the three databases, including duplicates (see Fig. 1). After duplicates were removed 120 papers remained.

Screening process

The PRISMA flow diagram presented in Fig. 1 (Page et al., 2021) provides a full account of the screening process. Books, book chapters, conference papers and reports were excluded after abstract review limiting the results to 78 journal articles. A further 24 papers were excluded as they were not Australian (2), were not addressing integration or were not school based (22). There were four related to preschool and aligning with the exclusion criteria, the decision was made to also exclude them. Abstract review also resulted in 19 papers being considered to have a more conceptual or theoretical focus rather than research involving STEM integration in practice, that is, implemented with students in school settings. Twenty nine remained for review. Full paper review resulted in exclusion of a further seven papers, with four not being Australian based, one an editorial, another

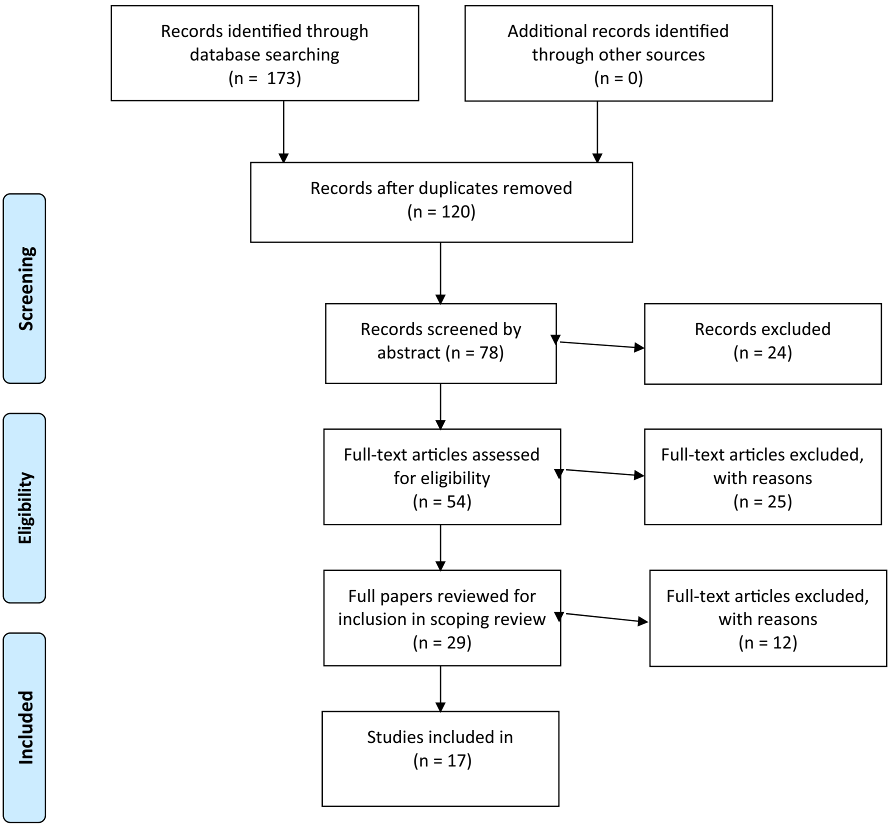

Fig. 1 PRISMA flow chart of literature screening process

a scoping review and another conceptual and not practice based. A further five were removed with closer reading as they were not practice based leaving a total of 17 papers for review.

Coding and analysis

Each of the 17 papers included in the review were coded based on the structure of the research questions:

RQ1—Characteristics identified from the 17 papers included location (state, metropolitan versus non-metropolitan), type of school (primary/secondary, public/private), teacher, expert and student involvement in the study, methodologies used in the studies and areas of STEM that were the focus. Details for each paper were entered on a spreadsheet.
RQ2—Teaching strategies used were also entered on to the spreadsheet to determine the most common. These included Cooperative Learning, Project/Problem-Based Learning and Authentic Experiences. Other approaches noted included Inquiry, Student-centred Learning, Scaffolding, Higher Order Thinking and Modelling. The coded teaching strategies were iterated from an established STEM framework (Deehan & MacDonald, 2023a) and are described more fully in Appendix 1. As mentioned in the introduction, teaching strategies are typically used in conjunction with one another rather than in isolation to reflect the integrated nature of STEM learning. This means that total counts of teaching strategies exceeded the number of papers as most studies utilized multiple approaches.
RQ3—Reported impacts were noted for each study as to whether they were generally positive, indicating improvements in learners' conceptualisations of STEM, mixed in their findings or finding no improvements.

A collaborative, consensus approach to coding and analysis ensured interrater reliability (Clark et al., 2021). Table 2 presents the coding framework utilised for each of the research questions. The papers were coded individually on a spreadsheet according to the coding framework as shown in Table 2. Each of the six authors contributed to an initial round of coding wherein each paper was coded at least twice. Discrepancies were discussed and resolved across a series of meetings. Coding was finalised once each paper had been reviewed independently at least twice and discussed in a meeting with all authors. Codes were collated and checked before being compiled into results.

Results

A total of 17 papers were identified for inclusion in the review. The findings are organised under the three research questions guiding this scoping review.

Table 2 Coding framework for the research questions

Coding element	Description
RQ1—major characteristics	
Location	Location was defined both by Australian State/ Territory and remoteness. Coded states and territories included New South Wales, Queensland, Victoria, South Australia, Western Australia, Tasmania, the Northern Territory and the Australian Capital Territory Remoteness was derived from available information presented in the publications and was coded based on the Australian Remoteness Structure delineating major metropolitan cites, regional centres and remote communities (ABS, 2023)
Type of school	Types of school included the level of schooling and the sector. For this paper we coded primary schools (years K-6, ages 6–12) and secondary schools (years 6–12, ages 13–18). Based on the Australian School List (ACARA, 2023) schools were also coded as Government or Non-Government. In Australia, Non-Government schools mostly comprised Catholic and Independent schools
Teacher, student and expert involvement	The inclusion and number of teachers, students and experts involved. Students were young people aged between 6 and 18. Teachers were educators responsible for regular classroom instruction in a school setting. Experts may or may not have been involved in teaching processes but are defined as not being responsible for day-to-day instruction in typical settings (academics, scientists, community members, etc.)
Research methodologies	Research methods were coded as qualitative, quantitative or mixed methods. Qualitative methods focused on the experiences, perceptions, and behaviours of stakeholders through non-numerical data. Quantitative research utilised numerical data
STEM focus	Each STEM programme was analysed to determine whether or not each of the four major STEM disciplines (Science, Technology, Engineering & Mathematics) were present in the teaching and learning
RQ2—teaching strategies	
*Refer to Appendix 1 for a full framework of STEM teaching strategies	
RQ3—Reported impacts	
Framework or model	The presentation of a conceptual framework that could inform school STEM education practice or a model to inform or adapt for STEM education practice

Table 2 (continued)

Coding element		Description
Teacher and/or school impacts		Impacts relating to the teachers or schools involved in a STEM initiative. These may include improved teacher capacity, enhanced school culture, and/or improved educator dispositions
Student impacts	STEM conceptual understanding	These impacts referred to students' understanding of STEM as an integrated discipline (e.g. problem-based, creative, nonlinear, authentic)
	Discipline specific understanding	These impacts referred to discipline specific knowledge and understanding. For example, spatial reasoning skills in mathematics, design skills in engineering or questioning in science
	Skill development	These impacts referred to practical skills shown by students, such as planning, questioning, recording, trialling, evaluating, reflecting, utilising technology
	Engagement and/or attitude	These impacts referred to students' overall dispositions towards STEM learning, including attitudes, willingness to participate, aspirations, beliefs

RQ1—major characteristics

Characteristics identified from the 17 papers included location (state, metropolitan versus non-metropolitan), type of school (primary/secondary, public/private), teacher, expert and student involvement in the study, methodologies used in the studies and areas of STEM that were the focus. These characteristics are described in the sub-sections below.

Location and school type

A total of 47 schools were involved in the projects across the 17 papers. As reported in the papers five were secondary focused, nine papers were primary focused and three included both. Eight of the studies involved schools in metropolitan areas, two in rural or regional areas and four both metropolitan and regional schools. In three papers state school locations were not stated. The schools involved were from across the country with five from Queensland, three each from Victoria and Western Australia, and one each from New South Wales and South Australia. Eight of the papers involved schools that were identified as public or government schools, two involved non government schools and three both government and non government. In four papers this was not stated. The schools involved were predominantly primary, metropolitan, government schools.

Teacher, student and expert involvement

Overall the number of teachers involved was reported across 11 of the papers, with a total of 114, a range of 1–34 per study and an average of ten. The total number of students involved was 2062, with a range of 4–198 and an average of 110. In one paper, the numbers of teachers and students were not reported (Wilson, 2021). Six papers did not mention how many teachers were involved and two did not give the number of students involved.

Many of the projects, 14 in total, involved ‘experts’ from outside the school such as scientists and engineers. These included involvement of academics in nine projects, three projects involved engineers or engineering undergraduates and one included preservice teachers, two involved community representatives such as an apiarist in one case and Aboriginal community representatives in another. In three studies experts were not involved (Falloon et al., 2022; Fowler et al., 2021 and Mildenhall et al., 2019). One of these was a robotics club (Falloon et al., 2022), Fowler et al. (2021) outlined five technologically themed activities over a week and Mildenhall et al. (2019) described an experimental social justice design project.

Methodologies used

The research methodology in 13 papers was qualitative including four that were considered case studies, three included both qualitative and quantitative methods and one quantitative methods only using pre and post surveys (Howley & Roberts, 2020). The surveys in the mixed methods evaluations consisted of a series of statements surrounding attitudes, interests and perceptions, to which students or teachers indicated their level of agreement on a seven-point Likert scale. Qualitative data collection methods included notes, video and observation, interviews and focus groups.

STEM focus

The STEM focus of the projects involved in the studies included use of particular project ideas where discipline knowledge and skills could be applied. Seven papers reported that they were including all STEM areas, three reported being technology focused with links to mathematics and/or science, two had an engineering focus linked to mathematics and/or science, one technology and mathematics, one Science and Technology and one science focus with a research project. The relevance of science and mathematics through STEM was the focus of Xu et al. (2022) while Wilson (2021) had a STEM and Problem-based learning focus.

Projects employed to exhibit disciplinary skills included a range of robotics projects using technology, design and engineering such as LEGO WeDo (Blackley & Howell, 2019), Robotics clubs (Fallon et al., 2021) and Robotic engineering and 3D modelling (Fowler et al., 2021). Use of coding (Scratch) and robotics (coding robots) included identifying students' mathematical thinking while coding in Miller (2019).

Other practical projects included design and construction of an earthquake safe building (English et al., 2017) and designing shoes for refugees (Mildenhall et al., 2019), design of a Mars Rover vehicle, investigating the scientific and societal implications of a pandemic, building a rollercoaster to specification and creating a liveable Minecraft world for a hypothetical exoplanet with extreme weather conditions (Wilson, 2021).

3D design and printing were discussed in Falloon et al. (2022) and Forbes et al. (2021) as applications of design and technology. Statistics were used for a project in which bicycle related emergency hospital admissions data for children aged under 15 years was analysed (Scott-Parker & Barone-Nugent, 2019) and in a project on electric vehicles (Howley & Roberts, 2020). Makerspace was discussed in four papers with extensive consideration in Sheffield et al. (2017) followed by Lang et al. (2018), Falloon et al. (2022) and Forbes et al. (2021).

RQ2—teaching strategies

Each of the 11 identified teaching strategies was represented in at least 4 studies. Figure 2 presents the counts for each teaching strategy in descending order of frequency within the selected publications. Cooperative Learning (14), Project/Problem-Based Learning (12), and Authentic Experiences (12) were the most common teaching strategies employed within the research outputs (Fig. 2). The complementary nature of these three broad approaches is evidenced by the fact that all three

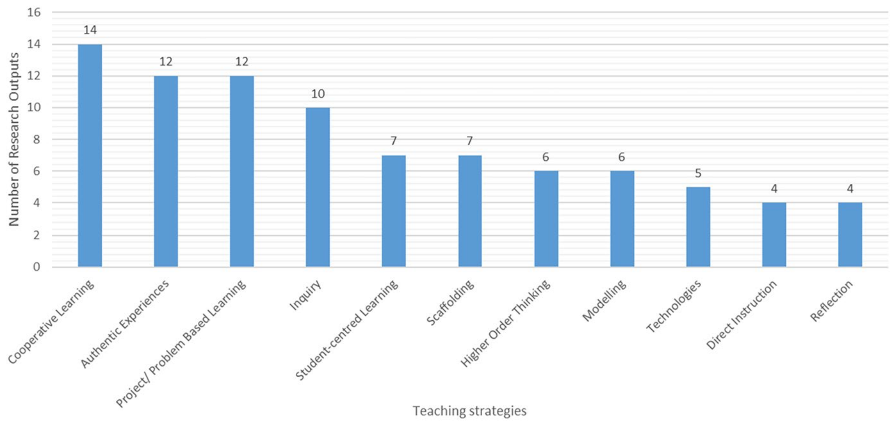

Fig. 2 Counts of STEM teaching approaches

appear in 8 (47%) research outputs; suggesting that cooperative learning, project/ problem-based learning and authentic contexts are foundational approaches to Australian STEM education practice. For example, English and King (2015) reported on an authentic programme supported by professional engineers wherein 63-year 4 students worked cooperatively on an aerospace problem. The participating students were able to engage in the interactive design and reflection processes whilst applying both their mathematics and science content knowledge. Forbes et al. (2021) investigated a similar design process model applied through 3D design and printing activities targeted at early primary learners (5–8), with results showing improvement in the children's STEM skills and overall engagement.

Mildenhall et al. (2019) established an authentic problem-based context based on an important issue of social justice, helping refugees to acquire shoes, which served as a catalyst for a cooperative and highly reflective STEM programme for a year 3 class. This project presented a model for how disciplinary skills can be explicitly developed in a STEM programme to enhance learners' skills and attitudes. Clearly, authentic, design/problem/project-based learning context driven by meaningful, extended cooperative learning are foundational to the enactment of STEM principles in classroom settings.

Less common, but still relatively prominent approaches to STEM education included Inquiry (10), Student-centred Learning (7), Scaffolding (7), Higher Order Thinking (6), and Modelling (6). Inquiry learning often overlapped with the broader Authentic Experiences and/or Project-problem-based learning (e.g. Falloon et al., 2021; Wilson, 2021) as a means of students obtaining knowledge actively with varying levels of support ranging from direct mentoring (Scott-Parker & Barone-Nugent, 2019) through to open inquiry with minimal assistance (Lang et al., 2018). Similarly to previous research (Deehan & MacDonald, 2023a), student-centred learning was often less detailed and seemed to function more as a complementary expression of researchers' STEM education values. However, Falloon et al. (2021) provided a detailed account of how learners' preferences and choices were incorporated into a more flexible programme; making the notion of student-centred learning more tangible for the reader. Possibly in acknowledgement of the need for explicit teaching to maximise the educational benefits of STEM learning (Falloon et al., 2021; Forbes et al., 2021; Fowler et al., 2021; Mildenhall et al., 2019), some STEM programmes featured scaffolding and modelling to support students. For example, Blackley and Howell (2019) described an overarching backward faded scaffolding (e.g. Slater et al., 2008) wherein the participating year 4 students received intensive teacher support before transitioning into collaborative problem solving in the Lego WeDo programme.

RQ3—reported impact

The majority (93%) of the contributions and findings made across the sampled research outputs were positive. The various STEM initiatives presented across the 17 research outputs were linked to improvements in learners' conceptualisations of STEM (e.g. Scott-Parker & Barone-Nugent, 2019), discipline specific knowledge (e.g. Howley & Roberts, 2020), STEM skills (e.g. English et al., 2013) and overall dispositions towards STEM (e.g. Mildenhall et al., 2019). Table 3 presents a findings matrix from the 17 analysed research articles. Only three studies reported any mixed outcomes in their findings. In what could be considered emblematic of existing concerns regarding discipline integrity in broad STEM programmes (Bybee, 2013; McComas & Burgin, 2020), two of the evaluated STEM projects were shown not to improve participants' discipline specific skills (Falloon et al., 2022; Fowler et al., 2021). Indeed, Falloon et al. (2022) found that although the design-based makerspaces project resulted in improvements in lower primary students' STEM skills and dispositions, explicit and targeted teaching was required to develop the students' discipline knowledge. Similarly, research has shown that immersion in a feminised STEM makerspace did not inherently lead to a sample of year 5 and 6 learners incorporating their new STEM learning into their previous schemas (Sheffield et al., 2017).

The findings extended beyond student learning outcomes through frameworks and models for STEM learning practice. A number of the research outputs included in this review have provided scholarly evidence for the viability of STEM frameworks such as: an Engineering Design Process (English et al., 2013, 2017), a Maker Literacies Framework (Forbes et al., 2021) and a framework for Collaborative Learning in Schools (Lang et al., 2018). A model for sophisticated multidisciplinary integration can be seen in Mildenhall et al.'s (2019) social justice and equity oriented programme.

Six of the research outputs (35.3%) examined the broader impact of STEM learning initiatives on the school contexts within which they were situated. Educators reported positive outcomes from their engagement in STEM learning programmes (English et al., 2013), including more favourable attitudes towards STEM sub-disciplines such as statistics (Howley & Roberts, 2020), feelings of connection with universities (Howley & Roberts, 2020), and feeling more prepared for STEM classroom teaching (Lang et al., 2018). Falloon et al.'s (2021) case studies of schools'

Table 3 Findings matrix derived from the 17 papers

Citation	Framework or model	Teacher and/or school	Student findings			
			STEM conceptual understanding	Discipline specific understanding	Skill development	Engagement and/or attitude
Blackley and Howell (2019)	1					
English and King (2015)					1	1
English et al., (2013)	1	1	1		1	
English et al., (2017)	1					
Falloon et al., (2021)		1				
Falloon et al., (2022)				1*	1	1
Forbes et al., (2021)	1				1	1
Fowler et al., (2021)				1*	1	1
Howley and Roberts (2020)		1		1		1
Lang et al., (2018)	1	1				1
Mildenhall et al., (2019)	1				1	1
Mildenhall et al., (2021)			1	1		1
Miller (2019)				1	1	
Sheffield et al., (2017)			1*		1	1
Scott-Parker and Barone-Nugent (2019)			1			1
Wilson (2021)		1				
Xu et al. (2022)		1	1			
Totals (% of outputs)	7 (39%)	6 (33%)	5 (28%)	5 (28%)	8 (44%)	10 (56%)

*Denotes a mixed or negative result

approaches to STEM enabled them to articulate the importance of broader contexts, '(t)he study highlights the complex interaction of professional learning, leadership, curriculum design, pedagogy, and school culture in establishing innovative STEM programmes in schools' (p. 110). Wilson's (2021) qualitative analysis of a single school's implementation of a project-based learning STEM programme highlighted the importance of school culture, scaffolding of active learning, and multi-dimensional assessment. Further nuance was added by Xu et al. (2022) as they provided evidence of the myriad of different STEM perspectives and backgrounds amongst educational professionals that must be understood and reconciled as a condition of school-wide STEM commitment.

Discussion

It is often challenging for teachers to transition STEM initiatives and policies into consistent classroom practices due to the complexity of modern teaching systems (Sheffield et al., 2018) and the nebulous nature of STEM education (Blackley & Howell, 2019; Rennie et al., 2018). To provide some clarity in this space, this scoping review has sought to explore how integrated STEM in Australian K-12 settings is taught and reported in academic literature. The following discussion will address the research questions sequentially through discussion of the characteristics, teaching strategies and reported impacts within the 17 research outputs. The discussion of the findings will be supplemented with an outline of the research and teaching implications and an overview of the limitations of this scoping review.

Major characteristics of research that has been conducted on integrated STEM programmes in Australian schools

It appears that the reliance on external experts in the analysed literature (88%), in the form of academics (e.g. Blackley & Howell, 2019), engineers (e.g. English & King, 2015), scientists (e.g. Scott-Parker & Barone-Nugent, 2019), and community stakeholders (e.g. Falloon et al., 2021), may be limiting the sustainability, scalability and ecological validity of this sub-field of STEM education. This is not to say that worthwhile contributions have not been made. The projects analysed have had positive impacts on school STEM learning cultures (Wilson, 2021) and individual teacher STEM dispositions (Xu et al., 2022). Additionally, it could be posited that the reported collaborations between academics and teachers highlighted would have short- and long-term benefits for participating teachers (Howley & Roberts, 2020; Lang et al., 2018) that could inform more scalable initiatives and professional development programmes in the future. This means research in this space can help to enhance teachers' abilities to integrate STEM into their teaching (e.g. Jacobs, 2022).

However, both the willingness of and opportunity for school leaders and teachers to engage with external stakeholders in the delivery of high-quality STEM education is indicative of beneficial cultural, systemic and professional factors that are unlikely to be representative of more typical school environments. Indeed, the provision of high-quality STEM education is hindered by systemic challenges of time (Crump, 2005; Jenkinson & Benson, 2010), resourcing (Gonski, 2011; Rowe & Perry, 2020), socio-economic inequity (Halsey, 2018; Sullivan et al., 2018), and crowded curricula (Akar, 2018; APPA, 2014) that are not fully addressed in most of the research outputs; many of which inadvertently present more idealised education contexts. Future research should focus on staffing profiles, school resources and procedures that are more reflective of schools within wider target populations. Indeed, many schools are not adequately staffed with capable and qualified STEM teachers (DISR, 2023; Marginson et al., 2013).

It is also recommended that more longitudinal and action research methodologies be utilised to examine the longer-term viability of STEM approaches in the absence of sophisticated external support. Such research will be vital to ensuring the scalability and sustainability of STEM education initiatives for systemic improvements. Fortunately, many teachers are willing to improve their STEM education practice with sufficient time, resourcing and professional development (Deehan & MacDonald, 2023b). According to recent national survey of 700 teachers, there was a nearly unanimous (98%) view that STEM learning was important, with a majority of primary teachers both with (79%) and without (59%) STEM qualifications feeling confident to teach STEM (DISR, 2023). However, only 36% of secondary educators without a STEM qualification expressed confidence.

Teaching strategies

Analysis of identified teaching approaches revealed a key triumvirate of Cooperative Learning (14), Project/Problem-Based Learning (12) and Authentic Experiences (12) which were often combined as pedagogical foundations for STEM programmes. Not only do these approaches align clearly with established conceptualisations of effective STEM integration (Guzey et al., 2016; Sanders, 2012) but they have well-established evidence bases in education research beyond this scoping review (e.g. Aubusson et al., 2015, 2019; Deehan et al., 2022). Authentic STEM experiences have been shown to improve students' STEM skills and dispositions (Roberts et al., 2018; Zhu et al., 2023), with project/problem-based learning now widely considered 'best practice' (Pressick-Kilborn et al., 2021; Thibaut et al., 2018). Interestingly, a two-year longitudinal investigation showed that achievement, dispositional and social gains experienced by a sample of 204 primary learners in a cooperative learning project were retained as they transitioned into high school (Thurston et al., 2010). As a field that is often plagued by a lack of conceptual clarity both in terms of the timing, extent and nature of integration and how discreet STEM disciplines are arranged and emphasised (MacDonald et al., 2023; Ong et al., 2016; Ring et al., 2017), a broad-based pedagogical commitment to cooperative learning and project/problem-based learning in authentic contexts could aid in ensuring the considerable potential of STEM learning is realised in typical classroom settings. Such a commitment could be supported by accessible professional development opportunities to aid classroom teachers to incorporate strong STEM approaches in ways that are manageable and sustainable.

Current professional development in STEM is varied in both opportunities (Burke et al., 2022) and accreditation requirements (ACT TQI, 2022; NSW ESA, 2017; QCT, 2022; TRBNT, 2022), so a clearer systemic commitment to effective STEM approaches via professional development could enhance STEM learning trajectories at scale. This review advances this argument as the literature reviewed highlights the benefits of external experts working with teachers and students in STEM education. Recent research has shown that Australian teachers feel they need access to more professional development opportunities in STEM (Deehan & MacDonald, 2023b), with many models of STEM professional development reporting positive influences on teachers' STEM dispositions and capabilities (MacDonald et al., 2023; Morris et al., 2021) There is another issue of scalability as methodologies and findings can be emphasised over the pedagogical detail in STEM programmes in the process of academic publication (e.g. Sheffield et al., 2017; Xu et al., 2022). However, the work of Mildenhall et al. (2021) is a strong example of how pedagogical and research detail can be balanced effectively in an academic publication.

Reported impact

The STEM programmes analysed in this scoping review reported positive outcomes for participants. Across the selected publications, learners displayed better attitudes towards STEM ($n=10$) (e.g. Mildenhall et al., 2019), conceptual understandings of STEM ($n=4$) (e.g. Scott-Parker & Barone-Nugent, 2019), and STEM skills ($n=8$) (e.g. Forbes et al., 2021) after participating in STEM programmes; suggesting a myriad of models for effective STEM education in schools are becoming available to assist in realising the potential benefits of effective STEM education at scale. It is noteworthy that two of the five studies that investigated the impacts of STEM programmes on discipline specific understandings showed mixed results (Falloon et al., 2022; Fowler et al., 2021). This accords with previously espoused views that STEM as a broad educational concept has the potential to erode the integrity of its distinct disciplines, as the unique requirements of disciplines such as science and mathematics could be diluted in broader STEM programmes (e.g. Anderson et al., 2020; English, 2015; Moore et al., 2014). The higher order skills and conceptual benefits associated with the reviewed STEM programmes lends credence to the notion that STEM education should build upon disciplinary foundations as it expands higher order thinking (Rennie et al., 2018). It is incumbent upon policy makers and educational leaders to consider how 'fault lines' or transition points between discipline learning and STEM learning can be identified and utilised for positive learning outcomes. A potential avenue would be to consider STEM education through skills and types of cognition (Sheffield et al., 2017) rather than through a purely disciplinary lens.

Implications for practice and research

There are implications for practitioners and researchers that merit consideration. For educators, it appears that cooperative learning, project/problem-based learning, and authentic experiences could serve as an evidence-based pedagogical foundation for enabling their students to reap the benefits of STEM education. As the scoped literature presents many viable models for effective STEM practice that could be adapted for different contexts, it would be worthwhile for the stakeholders to transition from 'what works' to 'how' educators can be supported in the delivery of effective STEM education. Central to such a transition would be to focus on scalable and sustainable initiatives that can be employed by typical classroom educators that are not yet fully represented in the scholarly literature. Indeed, some researchers have already begun to investigate school culture (Wilson, 2021) and teacher traits (Xu et al., 2022) as they relate to Australian STEM education. It would be advisable for curriculum writers and policy makers to be more explicit about the desired pedagogical approaches to STEM education. A core challenge is that the integrated nature of STEM learning is not always meaningfully reflected in curriculum documents wherein science, technology, engineering, and mathematics are often separated (ACARA, 2021). The tension between integrated STEM and discipline integrity is a longstanding point of tension in the scholarly literature (Blackley & Howell, 2019; English, 2015) that present a clear challenge to the wider uptake of STEM teaching approaches reported upon in this literature review and elsewhere. In fact, this siloing of STEM disciplines presents a greater structural impediment as students advance from more fluid learning environments in their early years through to discreet subjects with separate teachers and learning spaces in high school. Promisingly, recent research has shown integrated STEM units integrated into daily classroom activities can enhance students' core STEM skills whilst overcoming systemic curricular challenges (Jacobs, 2022). Additionally, larger scale and/or longitudinal research should be pursued to improve the representativeness and generalisability of this field of STEM education research.

Limitations

Methodological and contextual factors limit the utility of this scoping review. This review is limited by the relatively open and non-exhaustive nature of the scoping review methodology. For example, it is quite likely that grey literature beyond the scope of this review could provide valuable insights into Australian STEM education in K-12 settings. The tight focus on Australian research greatly diminishes the potential generalisability of the findings to other national contexts. Furthermore, although the coding procedures were collaborative and robust, they were limited by both the conceptualisations of the research team and the inherently incomplete information provided in the publications. Selection and reporting bias are also likely hindering factors as potentially relevant STEM research publications could have been presented as integrated disciplinary programmes in ways that would have eluded the search strategy.

Conclusion

This scoping review has been conducted at a pivotal time as Australia has embarked on a series of major STEM reforms and initiatives over the past decade. The 17 research outputs reporting on K-12 STEM programmes were varied in terms of year levels and programme designs. The overwhelming majority of outputs reported positive learner outcomes because of STEM programmes. A core triumvirate of pedagogical approaches in cooperative learning, project/problem-based learning and authentic experiences emerged across the programmes. However, the overreliance on external experts in the scoped literature limits the transferability and ecological validity of this emerging subfield of STEM education research. With this scoping review presenting contemporary evidence of effective Australian STEM education practices, there is now a parallel need for stakeholders to consider how educators can be supported to teach high-quality STEM at scale for the benefit of all Australian students.

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References

ABS (Australian Bureau of Statistics). (2023). Remoteness Areas - Australian Statistical Geography Standard (ASGS) Edition 3. Retrieved from https://www.abs.gov.au/statistics/standards/australian-statistical-geography-standard-asgs-edition-3/jul2021-jun2026/remoteness-structure/remoteness-areas

ACARA (Australian Curriculum, Assessment and Reporting Authority). (2016). ACARA STEM Connections Project Report. https://www.australiancurriculum.edu.au/resources/stem/stem-report/

ACARA (Australian Curriculum, Assessment and Reporting Authority). (2021). *Australian Curriculum: Foundation to Year 10*. https://www.australiancurriculum.edu.au/f-10-curriculum/

ACARA (Australian Curriculum, Assessment and Reporting Authority). (2023). *Australian Schools List*. Retrieved from https://asl.acara.edu.au/home

ACT TQI (Teacher Quality Institute). (2022). *Professional Learning*. Australian Capital Territory. Retrieved from https://www.tqi.act.edu.au/for-teachers/Maintaining-Registration

Akar, H. (2018). The relationships between quality of work life, school alienation, burnout, affective commitment and organizational citizenship: A study on teachers. *European Journal of Educational Research, 7*(2), 169–180. https://doi.org/10.12973/eu-jer.7.2.169

Anderson, J. (2020). The STEM education phenomenon and its impact on school curriculum. *Curriculum Perspectives, 40*(2), 217–223. https://doi.org/10.1007/s41297-020-00107-3

Anderson, J., English, L., Fitzallen, N., & Symons, D. (2020). The contributions of mathematics education researchers to the current STEM education agenda. In J. Way, C. Attard, J. Anderson, J. Bobis, H. McMaster, & K. Cartwright (Eds.), *Research in mathematics education in Australasia* (pp. 2016–2019). Springer.

Anderson, J., Wilson, K., Tully, D., & Way, J. (2019). 'Can we build the wind powered car again? students' and teachers' responses to a new integrated STEM curriculum. *Journal of Research in STEM Education, 5*(1), 20–39. https://doi.org/10.51355/jstem.2019.61

APPA (Australian Primary Principals Association). (2014). *The overcrowded primary curriculum: A way forward*. Retrieved from https://appa.asn.au/advocacy/submissions-position-papers/

Arksey, H., & O'Malley, L. (2005). Scoping studies: Towards a methodological framework. *International JOurnal of Social Research Methodology, 8*(1), 19–32. https://doi.org/10.1080/1364557032000119616

Aubusson, P., Skamp, K., Burke, P.F., Pressick-Kilborn, K., Ng, W., Palmer, T.A., Goodall, A. & Ferguson, J. (2019). *Primary connections: Linking science with literacy stage 6 research evaluation final report*, prepared for Steering Committee of Primary Connections, Australian Academy of Science, Retrieved December 22, 2021. https://opus.lib.uts.edu.au/handle/10453/134515

Aubusson, P., Schuck, S., Ng, W., Burke, P., & Pressick-Kilborn, K. (2015). *Quality learning and teaching in primary science and technology literature review*. Association of Independent Schools, New South Wales.

Australian Office of the Chief Scientist. (2014). *Science, Technology, Engineering and Mathematics: Australia's Future,* Commonwealth of Australia. https://www.chiefscientist.gov.au/2014/09/professor-chubb-releases-science-technology-engineering-and-mathematics-australias-future

Blackley, S., & Howell, J. (2019). The next chapter in the STEM education narrative: Using robotics to support programming and coding. *Australian Journal of Teacher Education, 44*(4), 51–64. https://doi.org/10.14221/ajte.2018v44n4.4

Burke, P. F., Palmer, T. A., & Pressick-Kilborn, K. (2022). Preferences for professional development in science among pre-and in-service primary teachers: A best-worst scaling approach. *Research in Science Education, 52*(6), 1791–1806. https://doi.org/10.1007/s11165-021-10030-w

Bybee, R. W. (2013). *The case for STEM education: Challenges and opportunities*. National Science Teachers Association Press.

Chin, C. (2007). Teacher questioning in science classrooms: Approaches that stimulate productive thinking. *Journal of Research in Science Teaching: THe Official Journal of the National Association for Research in Science Teaching, 44*(6), 815–843. https://doi.org/10.1002/tea.20171

Chiu, T. K., Ismailov, M., Zhou, X., Xia, Q., Au, C. K., & Chai, C. S. (2023). Using self-determination theory to explain how community-based learning fosters student interest and identity in integrated STEM education. *International Journal of Science and Mathematics Education*. https://doi.org/10.1007/s10763-023-10382-x

Clark, T., Foster, L., Sloan, L., & Bryman, A. (2021). *Bryman's Social Research Methods*. Oxford University Press.

Education Council. (2015). *National STEM School Education Strategy: A comprehensive plan for science, technology, engineering and mathematics education in Australia*. Education Council. https://www.dese.gov.au/education-ministers-meeting/resources/national-stem-school-education-strategy

Education Council. (2018). *Optimising STEM industry-school partnerships: Inspiring Australia's next generation*. Education Council. Canberra, Australian Capital Territory: Department of Education, Skills and Employment. https://www.education.gov.au/education-ministers-meeting/resources/optimising-stem-industryschool-partnerships-final-report

Crump, S. (2005). Changing times in the classroom: Teaching as a 'crowded profession.' *International Studies in Sociology of Education, 15*(1), 31–48. https://doi.org/10.1080/09620210500200130

Davis, K., Fitzgerald, A., Power, M., Leach, T., Martin, N., Piper, S., Singh, R., & Dunlop, S. (2023). Understanding the conditions informing successful STEM clubs: What does the evidence base tell us? *Studies in Science Education, 59*(1), 1–23. https://doi.org/10.1080/03057267.2021.1969168

Deehan, J., & MacDonald, A. (2023a). Examining the metropolitan and non-metropolitan educational divide: Science teaching efficacy beliefs and teaching practices of Australian primary science educators. *Research in Science Education, 53*(5), 889–917. https://doi.org/10.1007/s11165-023-10113-w

Deehan, J., & MacDonald, A. (2023b). Australian teachers' views on how primary science education can be improved. *Australian Educational Researcher*. https://doi.org/10.1007/s13384-023-00638-4

Deehan, J., MacDonald, A., & Morris, C. (2022). A scoping review of interventions in primary science education. *Studies in Science Education*. https://doi.org/10.1080/03057267.2022.215499=

(DISR) Department of Industry, Science and Resources. (2023). *Teachers and career advisers' perceptions and attitudes to STEM*. Australian Government. Retrieved from https://www.industry.gov.au/publications/stem-equity-monitor/primary-and-secondary-school-data/teachers-and-career-advisers-perceptions-and-attitudes-stem

English, L. (2015). STEM: Challenges and opportunities for mathematics education. In T. Muir, J. Wells, & K. Beswick (Eds). *Proceedings of the 39th meeting of the International Group for the Psychology of Mathematics Education,* 4–18. Available online: https://eprints.qut.edu.au/87506/3/87506.pdf

English, L. (2016a). Advancing mathematics education research within a STEM environment. In K. Maker, S. Dole, J. Visnovska, M. Goos, A. Bennison, & K. Fry (Eds.), *Research in mathematics education in Australasia 2012–2015* (pp. 353–371). Springer.

English, L. D. (2016b). STEM education K-12: Perspectives on integration. *International Journal of STEM Education*. https://doi.org/10.1186/s40594-016-0036-1.pdf

English, L. D., Hudson, P., & Dawes, L. (2013). Engineering-based problem solving in the middle school: Design and construction with simple machines. *Journal of Pre-College Engineering Education Research, 3*(2), 43–55. https://doi.org/10.7771/2157-9288.1081

English, L. D., & King, D. T. (2015). STEM Learning through Engineering Design: Fourth- Grade Students' Investigations in Aerospace. *International Journal of STEM Education, 2*(1), 1. https://doi.org/10.1186/s40594-015-0027-7

English, L. D., King, D., & Smeed, J. (2017). Advancing integrated STEM learning through engineering design: Sixth-grade students' design and construction of earthquake resistant buildings. *Journal of Educational Research, 110*(3), 255–271. https://doi.org/10.1080/00220671.2016.1264053

Falloon, G., Forbes, A., Stevenson, M., Bower, M., & Hatzigianni, M. (2022). STEM in the Making? Investigating STEM learning in junior school makerspaces. *Research in Science Education, 52*(2), 511–537. https://doi.org/10.1007/s11165-020-09949-3

Falloon, G., Stevenson, M., Beswick, K., Fraser, S., & Geiger, V. (2021). Building STEM in Schools: An Australian Cross-case Analysis. *Educational Technology & Society, 24*(4), 110–122. https://doi.org/10.30191/ETS.202110_24(4).0009

Forbes, A., Falloon, G., Stevenson, M., Hatzigianni, M., & Bower, M. (2021). An analysis of the nature of young students' STEM learning in 3D technology-enhanced makerspaces. *Early Education and Development, 32*(1), 172–187. https://doi.org/10.1080/10409289.2020.1781325

Fowler, S., Cutting, C., Kennedy, J. P., Leonard, S. N., Gabriel, F., & Jaeschke, W. (2021). Technology enhanced learning environments and the potential for enhancing spatial reasoning: A mixed methods study. *Mathematics Education Research Journal, 34*(4), 887–910. https://doi.org/10.1007/s13394-021-00368-9

Gee, K. A., & Wong, K. K. (2012). A cross national examination of inquiry and its relationship to student performance in science: Evidence from the Program for International Student Assessment (PISA) 2006. *International Journal of Educational Research, 53*, 303–318. https://doi.org/10.1016/j.ijer.2012.04.004

Georgiou, H. (2023). Are we really falling behind? Comparing key indicators across international and local standardised tests for Australian high school science. *Research in Science Education, 53*, 1205–1220. https://doi.org/10.1007/s11165-023-10129-2

Godino, J. D., Batanero, C., Cañadas, G. R., & Contreras, J. M. (2016). Linking inquiry and transmission in teaching and learning mathematics and experimental sciences. *Acta Scientiae, 18*(4), 29–47.

Gonski, D. (2011). *Review of Funding for Schooling*. Canberra ACT: Commonwealth of Australia. https://www.education.gov.au/school-funding/resources/review-funding-schooling-final-report-december-2011

Gough, A. (2021). All STEM-Ed up: Gaps and silence around ecological education in Australia. *Sustainability, 13*, 3801. https://doi.org/10.3390/su1307380

Guzey, S. S., Moore, T. J., & Harwell, M. (2016). Building Up STEM: An analysis of teacher-developed engineering design-based STEM integration curricular materials. *Journal of Pre-College Engineering Education Research (j-PEER)*. https://doi.org/10.7771/2157-9288.1129

Halsey, J. (2018). *Independent review into regional, rural and remote education.* Canberra, Australia: Commonwealth of Australia. Retrieved from https://docs.education.gov.au/node/50281

Honey, M., Pearson, G., & Schweingruber, H. (2014). *STEM integration in K-12 education: Status, prospects and an agenda for research*. National Academies Press. https://doi.org/10.17226/18612

Howley, P., & Roberts, T. (2020). Engaging school students and educators with the practice of statistics. *Statistics Education Research Journal, 19*(1), 29–38. https://doi.org/10.52041/serj.v19i1.117

Hunter, J. (2020). Integrated STEM in Australian Public Schools: Opening up possibilities for effective teacher professional learning. In J. Anderson & Y. Li (Eds.), *Integrated approaches to STEM Education* (pp. 469–489). Springer. https://doi.org/10.1007/978-3-030-52229-2_25

Jacobs, B. (2022). Improving primary STEM education by integrating the Australian Curriculum. *Curriculum Perspectives, 42*, 135–143. https://doi.org/10.1007/s41297-022-00163-x

Jenkinson, K. A., & Benson, A. C. (2010). Barriers to providing physical education and physical activity in Victorian state secondary schools. *Australian Journal of Teacher Education, 35*(8), 1–17. https://doi.org/10.14221/ajte.2010v35n8.1

Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education, 3*, 1–11. https://doi.org/10.1186/s40594-016-0046-z

Lang, C., Powell, G., Ibrahim, F., & Moore, N. (2018). Connecting Teachers, Students and Pre- Service Teachers to Improve STEM Pathways in Schools. *International Journal of Innovation in Science and Mathematics Education, 26*(8), 45–66.

Macdonald, A., Danaia, L., Deehan, J., & Hall, A. (2023). STEM professional learning in early childhood education. *Journal of Early Childhood Teacher Education*. https://doi.org/10.1080/10901027.2023.2224251

Marginson, S., Tytler, R., Freeman, B., & Roberts, K. (2013). STEM: Country Comparisons. International comparisons of science, technology, engineering and mathematics (STEM) education. *Australian Academy of Learned Academies (ACOLA)*. Melbourne, Australia. https://acola.org/stem-country-comparisons-saf02/

Martin, A. J., Durksen, T. L., Williamson, D., Kiss, J., & Ginns, P. (2016). The role of a museum-based science education program in promoting content knowledge and science motivation. *Journal of Research in Science Teaching, 53*(9), 1364–1384. https://doi.org/10.1002/tea.21332

McComas, W. F., & Burgin, S. R. (2020). A critique of 'STEM' education. *Science & Education, 29*(4), 805–829. https://doi.org/10.1007/s11191-020-00138-2

Mildenhall, P., Cowie, B., & Sherriff, B. (2019). A STEM extended learning project to raise awareness of social justice in a Year 3 primary classroom. *International Journal of Science Education, 41*(4), 471–489. https://doi.org/10.1080/09500693.2018.1560514

Mildenhall, P., Sherriff, B., & Cowie, B. (2021). The Honey Bees Game: Engaging and Inspiring the Community with STEM. *Research in Science & Technological Education, 39*(2), 225–244. https://doi.org/10.1080/02635143.2019.1687440

Millar, V. (2020). Trends, Issues and Possibilities for an Interdisciplinary STEM Curriculum. *Science and Education, 29*(4), 929–948. https://doi.org/10.1007/s11191-020-00144-4

Miller, J. (2019). STEM education in the primary years to support mathematical thinking: Using coding to identify mathematical structures and patterns. *ZDM - Mathematics Education, 51*(6), 915–927. https://doi.org/10.1007/s11858-019-01096-y

Moore, T. J., Stohlmann, M. S., Wang, H., Tank, K. M., Glancy, A. W., & Roehrig, G. H. (2014). Implementation and integration of engineering in K-12 STEM education. In S. Purzer, J. Strobel, & M. Cardella (Eds.), *Engineering in pre-college settings: Research into practice* (pp. 35–60). Purdue University Press.

Morris, J., Song, Y., Soloway, E., & Norris, C. (2021). Teacher professional development in STEM education. *Journal of Educational Technology & Society, 24*(4), 81–85.

Murphy, S., MacDonald, A., Danaia, L., & Wang, C. (2019). An analysis of Australian STEM education strategies. *Policy Futures in Education, 17*(2), 122–139. https://doi.org/10.1177/1478210318774190

Newhouse, C. P. (2017). STEM the boredom: Engage students in the Australian curriculum using ICT with problem-based learning and assessment. *Journal of Science Education and Technology, 26*, 44–57. https://doi.org/10.1007/s10956-016-9650-4

NSW Education Standards Authority (NESA). (2017). *Professional Development Requirements*. NSW Education Standards Authority, Sydney. Retrieved from https://educationstandards.nsw.edu.au/wps/portal/nesa/teacher-accreditation/professional-development/pd-requirements

Ong, E. T., Ayob, A., Ibrahim, M. N., Adnan, M., Shariff, J., & Ishak, N. (2016). The effectiveness of an in-service training of early childhood teachers on STEM integration through Project-Based Inquiry Learning (PIL). *Journal of Turkish Science Education, 13*(3), 44–58.

Ozogul, G., Miller, C. F., & Reisslein, M. (2019). School fieldtrip to engineering workshop: Pre-, post-, and delayed-post effects on student perceptions by age, gender, and ethnicity. *European Journal of Engineering Education, 44*(5), 745–768. https://doi.org/10.1080/03043797.2018.1518408

Page, M., McKenzie, J., Bossuyt, P. M., Boutron, I., Hoffmann, T., Mulrow, C., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., & Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ, 372*(71), 1–9. https://doi.org/10.1016/j.jclinepi.2021.03.001

Peters, M., Marnie, C., Tricco, A., Pollock, D., Munn, Z., Alexander, L., McInerney, P., Godfrey, C., & Khalil, H. (2020). Updated methodological guidance for the conduct of scoping reviews. *JBI Evidence Synthesis, 18*(10), 2119–2126. https://doi.org/10.11124/JBIES-20-00167

Pressick-Kilborn, K., Silk, M., & Martin, J. (2021). STEM and STEAM education in Australian K–12 schooling. *Oxford Research Encyclopedia of Education*. https://doi.org/10.1093/acrefore/9780190264093.013.1684

QCT (Queensland College of Teachers). (2022). *Continuing Professional Development (CPD) Requirements*. Retrieved from https://www.qct.edu.au/professional-development/requirements

Redman, C. (2017). Would increasing engineering literacies enable untapped opportunities for STEM education? *Theory into Practice, 56*(4), 318–326. https://doi.org/10.1080/00405841.2017.1350493

Rennie, L., Venville, G., & Wallace, J. (2018). Making STEM curriculum useful, relevant and motivating for students. In R. Jorgensen & K. Larkin (Eds.), *STEM education in the junior secondary: The state of play* (pp. 91–110). Springer.

Ring, A. E., Dare, E. A., Crotty, E. A., & Roehrig, G. H. (2017). The evolution of teacher conceptions of STEM education throughout an intensive professional development experience. *Journal of Science Teacher Education, 28*(5), 444–467. https://doi.org/10.1080/1046560X.2017.1356671

Roberts, T., Jackson, C., Mohr-Schroeder, M. J., Bush, S. B., Maiorca, C., Cavalcanti, M., & Cremeans, C. (2018). Students' perceptions of STEM learning after participating in a summer informal learning experience. *International Journal of STEM Education, 5*(1), 1–14. https://doi.org/10.1186/s40594-018-0133-4

Roehrig, G. H., Dare, E. A., Ring-Whalen, E., & Wieselmann, J. R. (2021). Understanding coherence and integration in integrated STEM curriculum. *International Journal of STEM Education, 8*(1), 2. https://doi.org/10.1186/s40594-020-00259-8

Rosicka, C. (2016). *Translating STEM education research into practice*. ACER: Melbourne, Australia. Retrieved from http://research.acer.edu.au/professionaldev/10

Rowe, E., & Perry, L. B. (2020). Inequalities in the private funding of public schools: Parent financial contributions and school socioeconomic status. *Journal of Educational Administration and History, 52*(1), 42–59. https://doi.org/10.1080/00220620.2019.1689234

Sanders, M. (2012). *Integrative STEM education as "best practice"*. Paper presented at the 7th Biennial International Technology Education Research Conference, Queensland, Australia. https://vtechworks.lib.vt.edu/bitstream/handle/10919/51563/SandersiSTEMEdBestPractice.pdf?sequence=1

Scott-Parker, B., & Barone-Nugent, E. (2019). Enlightening STEM Engagement during High School – Make It Real Banana Peel. *Journal of STEM Education: Innovations and Research, 20*(1), 5–10.

Sgro, C. M., Bobowski, T., & Oliveira, A. W. (2020). Current praxis and conceptualization of STEM education: A call for greater clarity in integrated curriculum development. In V. Akerson & G. Buck (Eds.), *Contemporary trends and issues in science education: Critical questions in STEM education* (pp. 185–210). Springer. https://doi.org/10.1007/978-3-030-57646-2_11

Sheffield, R. S., Koul, R., Blackley, S., Fitriani, E., Rahmawati, Y., & Resek, D. (2018). Transnational examination of STEM education. *International Journal of Innovation in Science and Mathematics Education, 26*(8), 67–80.

Sheffield, R., Koul, R., Blackley, S., & Maynard, N. (2017). Makerspace in STEM for girls: A physical space to develop twenty-first-century skills. *Educational Media International, 54*(2), 148–164. https://doi.org/10.1080/09523987.2017.1362812

Slater, S. J., Slater, T. F., & Shaner, A. (2008). Impact of backwards faded scaffolding in an astronomy course for pre-service elementary teachers based on inquiry. *Journal of Geoscience Education*, *56*(5), 408–416. https://doi.org/10.5408/jge_nov2008_slater_408.

Struyf, A., De Loof, H., Boeve-de Pauw, J., & Van Petegem, P. (2019). Students' engagement in different STEM learning environments: Integrated STEM education as promising practice? *International Journal of Science Education, 41*(10), 1387–1407. https://doi.org/10.1080/09500693.2019.1607983

Sullivan, K., Perry, L., & McConney, A. (2018). A comparison of rural educational disadvantage in Australia, Canada, and New Zealand using OECD's PISA. *SAGE Open, 8*(4), 1–12. https://doi.org/10.1177/2158244018805791

Thibaut, L., Ceuppens, S., De Loof, H., De Meester, J., Goovaerts, L., Struyf, A., & Depaepe, F. (2018). Integrated STEM education: A systematic review of instructional practices in secondary education. *European Journal of STEM Education, 3*(1), 1–12. https://doi.org/10.20897/ejsteme/85525

Thomson, S., Wernert, N., Rodrigues, S., & O'Grady, E. (2020). TIMSS Australia 2019: Highlights. *Australian Council for Educational Research*. https://doi.org/10.37517/978-1-74286-616-1

Thurston, A., Topping, K. J., Tolmie, A., Christie, D., Karagiannidou, E., & Murray, P. (2010). Cooperative Learning in Science: Follow-up from primary to high school. *International Journal of Science Education, 32*(4), 501–522. https://doi.org/10.1080/09500690902721673

TRBNT (Teacher Registration Board of the Northern Territory). (2022) *Evidence Guide: Full Registration Renewal Requirements*. Northern Territory Government. Retrieved from https://www.trb.nt.gov.au/system/files/uploads/files/2019/evidence-guide-for-renewal-of-full-registration-requirements-audit_0_0.pdf

Wilson, K. (2021). Exploring the challenges and enablers of implementing a stem project-based learning programme in a diverse junior secondary context. *International Journal of Science and Mathematics Education, 19*(5), 881–897. https://doi.org/10.1007/s10763-020-10103-8

Xu, L., Fang, S. C., & Hobbs, L. (2022). The Relevance of STEM: A Case Study of an Australian Secondary School as an Arena of STEM Curriculum Innovation and Enactment. *International Journal of Science and Mathematics Education, 21*(2), 667–689. https://doi.org/10.1007/s10763-022-10267-5

Zhu, C., Leung, C.O.-Y., Lagoudaki, E., Velho, M., Segura-Caballero, N., Jolles, D., Dufy, G., Maresch, G., Pagkratidou, M., & Klapwijk, R. (2023). Fostering spatial ability development in and for authentic STEM learning. *Frontiers in Education, 8*, 1. https://doi.org/10.3389/feduc.2023.1138607

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