Examining STEM Education Policy: Gaps Between Rhetoric and Reality in Schools and Initial Teacher Education

Marshman, Margaret; McMaster, Natalie; Scott, Joseph J; et.al.

Marshman, M., McMaster, N., Scott, J. J., Siostrom, E., & Strachan, A. (2025). Examining STEM Education Policy: Gaps Between Rhetoric and Reality in Schools and Initial Teacher Education. Research in Integrated STEM Education, 3(1), 24–48. https://doi.org/10.1163/27726673-bja00028
Document Type: Accepted Version

Link to Published Version: https://doi.org/10.1163/27726673-bja00028

Examining STEM Education Policy: Gaps Between Rhetoric and Reality in Schools and Initial Teacher Education

Margaret Marshman[a], Natalie McMaster[a], Joseph Scott[a], Erin Siostrom[b] Amy Strachan[a]

[a]School of Education and Tertiary Access, University of the Sunshine Coast, Sunshine Coast, Australia

[b] School of Education and Tertiary Access, University of the Sunshine Coast, Moreton Bay, Australia

Abstract

Developing a country's STEM capacity is vital for economic growth, technological innovation, and addressing complex global environmental and healthcare challenges. Individuals also need STEM capacity to function as informed citizens in modern society. However, there is misalignment between rhetoric and reality of STEM education in both schools and initial teacher education policy and practice. Through an analysis of curriculum documents for both schools and Initial Teacher Education, resources, and policy documents, an understanding of how integrated STEM education is documented in various jurisdictions was established. There were substantial differences between what the overarching policies and frameworks provided to schools as well as for initial teacher education accreditation. As students are making decisions about future directions in primary school, we argue that preservice teachers need a critical understanding of the purposes and pedagogies of 'STEM' education to teach interdisciplinary STEM on graduation and provide recommendations for future policy and research.

Key words primary initial teacher education, STEM education, integrated STEM

1 Introduction

Developing STEM (science, technology, engineering, and mathematics) capacity in schools is widely acknowledged as vital for a country's economic growth and competition, technological and research innovation, and addressing complex global environmental and healthcare challenges (Australian Government, 2023; Office of the Chief Scientist, 2023). Individuals also need STEM capacity to function as informed citizens in modern society. Globally, policy governing science and mathematics education at both school and tertiary levels and research in the STEM disciplines has moved towards a focus on STEM (Freeman et al., 2019). In Australia, for example, The *National STEM School Education Strategy (NSSES) 2016-2026* (Department of Education, Skills and Employment [DESE], 2015) was developed with two goals: ensuring students have strong STEM knowledge and skills when they finish school; and encouraging students to study challenging STEM subjects (Department of Education, Skills and Employment [DESE], 2015). *NSSES* was designed to assist Australian schools to deliver high quality STEM initiatives promoting the development of mathematical, scientific, digital literacy, problem solving, critical analysis and creative thinking skills (DESE, 2015; Queensland Curriculum Assessment Authority [QCAA], 2017).

NSSES (DESE, 2015) suggested strategies to improve initial teacher education (ITE) by supporting teacher confidence and STEM content expertise through implementation of a national literacy and numeracy test for preservice teachers, and recommendations for mandatory content requirements within ITE programs (DESE, 2015). While the plan's end date is fast approaching, the second action remains unmet, with no clarity surrounding this mandatory content. Subsequent policy initiatives have remained silent on the action. For example, the recent Teacher Educational Expert Panel (TEEP) (Department of Education, 2023) recommendations established by the Australian Government to provide direction to improve ITE in Australia offer no guidance for considerations of mandatory content within ITE programs regarding STEM education (Department of Education, 2023).

Barriers faced by primary preservice and in-service teachers when developing and delivering integrated STEM education, include lack of exposure to the theory and practice of integrated STEM education during ITE, low confidence in designing STEM-based learning experiences, and reticence from schools (Kurup et al., 2019; Wan et al., 2023). Until the education community better understands the nature of STEM integration within formal learning, its implementation may be unsuccessful (Dare, 2021). The Australian Curriculum (Australian Curriculum Assessment and Reporting Authority [ACARA], 2024) organises the STEM subjects (mathematics, science, and technologies) as discrete learning areas, each with their own set of curriculum descriptions and assessment standards adds to the challenge.

Primary schools are important for STEM education, with research highlighting that positive STEM experiences and exposure lead to improved engagement and achievement in later education (Author, 2023; Wan et al., 2023). Although some recommend placing specialist STEM teachers into primary schools (e.g. Prinsley and Johnston, 2015; State of Queensland Department of Education, 2016), Timms et al. (2018) warns that this is not the answer, calling for professional development that enables all primary teachers to build the confidence to translate the theory of integrated STEM education into concrete classroom activities and teaching concepts.. However, there is little research on STEM education within ITE and how this could advance Australian STEM education. By analysing policy and curriculum documents and resources for both schools and initial teacher education our project aimed to explore how integrated STEM education is documented in various jurisdictions.

Our research found that opportunities for pre-service and in-service primary teachers to develop STEM education capacity are limited. We argue that there is a pressing need for integrated STEM leadership, a unified understanding of STEM education, and improved coverage of integrated STEM education within ITE programmes. Equipping future primary teachers with the skills and confidence to design and deliver integrated STEM learning through ITE programs will better prepare both teachers and their students to meet the demands of a STEM-focused future.

2 Background

2.1 *Definitions of STEM Education*

Despite widespread agreement regarding the economic and social imperative of a STEM-skilled workforce (Department of Education, Skills and Employment, 2015), definitions of STEM and integrated STEM education remain contested (Kelley & Knowles, 2016; Bentley et al., 2022). STEM, introduced by the National Science Foundation in the late 1990s (Blackley & Howell, 2015), attracted increasing political focus as globalisation and the rise of technological innovation made the demand for a STEM-skilled workforce an economic imperative. In the past two decades, however, the meaning and focus of STEM has shifted. Early forms of the STEM agenda were enacted as S.T.E.M, where distinct discipline areas like science and mathematics were taught as siloed and separate subject areas (Moore & Smith, 2014). Later attempts to focus on integration of the distinct disciplines were conceptualised as S.t.e.M, or the integration of science and mathematics, largely ignoring technology and engineering (Strimel & Grubbs, 2016). From a national perspective, Australia's government policy refers to STEM education as "a broad field of distinct and complementary approaches to knowledge", (Office of the Chief Scientist, 2014, p.5). However, this fails to offer a clear framework for STEM education goals and teaching methodologies.

There is debate in the literature about what STEM education involves (see for example, Erduran, 2020; English, 2017). Many definitions centre on some form of integration of the four STEM areas, rather than teaching or learning associated with a single discipline (e.g., science or mathematics). Honey et al. (2014) suggested the definition of "working in the context of complex phenomena or situations on tasks that require students to use knowledge and skills from multiple disciplines" (p. 52). Shaughnessy (2013) is more specific with their definition that "STEM education refers to solving problems that draw on concepts and procedures from mathematics and science while incorporating the teamwork and design methodology of engineering and using appropriate technology" (p. 324). Bryan et al. (2015) believed that STEM integration needed to be *specific* and *intentional* identifying three forms of STEM integration: (a) learning experiences with multiple STEM learning objectives for the integrated content, (b) the learning objectives of the main content is supported by the integration of content from another, and (c) context integration where the context from one discipline is used for the learning objectives from another.

Vasquez (2014) though highlights the most important aspect of STEM education is that "[a]pplication is at the heart of STEM education" (p. 12) and described STEM as fitting on an inclined plane of increasing levels of integration. At a *disciplinary* level, the concepts are taught separately in siloed disciplines. With the *multidisciplinary* level the concepts and skills are taught separately through a common theme, whereas in the *interdisciplinary* level two or more disciplines are taught together thereby drawing connections between the knowledge and skills. In the final level, *transdisciplinary* students work on real world problems or projects learning and applying knowledge and skills from two or more disciplines (Vasquez, 2014).

Bentley et al. (2022) provides valuable insights into the ontological and epistemological relationships between the four STEM disciplines in the context of curriculum and pedagogy. While mathematics, technology, engineering, and science each have their own distinct subject matter and teaching methods, they share common approaches to knowledge, learning, and understanding. These include problem-solving, empirical and evidence-based reasoning, the use of modelling and abstraction, critical thinking and scepticism, collaboration and communication, and interdisciplinary connections. These shared epistemological dimensions can serve to unify the disciplines and guide students toward more effective learning and discovery. Thus, we contend that it is crucial to clarify the key epistemological dimensions of STEM education in Initial Teacher Education—the beliefs, processes, and strategies students use to acquire, understand, and apply knowledge. Building on these definitions described above, we propose that within ITE programmes, preservice teachers need clear examples of integrated STEM education that have meaningful links between disciplines, respecting their individual integrity while facilitating a holistic understanding of complex concepts and challenges.

1.2 *International perspectives*

STEM education is widely recognised as essential for a nation's prosperity and security (Li, 2014). However, recent studies indicate that by 2030, there will be a significant global shortage of workers in STEM fields (OECD, 2024). This challenge is compounded by the environmental and social issues of the twenty-first century, as well as a decline in STEM engagement in secondary and tertiary education in many Western countries (Australian Industry Group, 2015). Also, to successfully function in society individuals need STEM capability. As a result, there has been growing momentum for STEM education reform on a global scale.

In the USA, STEM education has been extensively supported with national policy and government funding to develop STEM focus and skills (Committee on STEM Education of the National Science and Technology Council, 2018), with a refreshed STEM education strategic plan outlining the importance of STEM teaching and learning addressing the need to prepare learners with the STEM skills to contribute to the wellbeing of their communities and secure desired STEM career opportunities (National Science and Technology Council, 2024). A recent study in USA calls for a more 'justice-centred' STEM education which aims to engage all students in multiple STEM subjects, focusing on their ability to explain and design solutions to pressing social challenges and their disproportionate impact on minoritised groups (Grapin et al., 2023).

In 2022, Europe also developed an integrated STEM teaching framework, with the incorporation of non-STEM subjects, supporting a 'holistic and systemic approach to education' (European Schoolnet, 2022, p.17). A *STEM Education Implementation Plan in Ireland* (Department of Education, 2023) emphasised the importance of STEM education being an integral part of Early Childhood learning and recommended a mandatory module on integrated STEM education for all initial teacher education courses and for all Early Years Education and Primary Teachers as part of their continuous professional development by 2026.

A framework from UK's department of science and technology (UK Government, 2023) focuses recommendations on fostering an inclusive, diverse, and welcoming environment in STEM education to meet the demand for STEM skills and to ensure equal opportunities to pursue STEM careers and equip the future workforce for the demands of the digital age. The framework highlights the action to understand which science and technology skills to prioritise within education, and to pursue the ambition for all young people to study Mathematics to 18 years of age. Finally, Scottish Schools Education Research Centre (SSERC), as identified in the latest STEM education training strategy (Scottish Government, 2022) highlights the successful provision of professional learning courses for Early Years practitioners and primary teachers with a focus on curriculum design, including digital skills and computing science, to support high-quality, relevant and contextualised STEM learning, teaching, and assessment, with a future action to use STEM education to refresh and strengthen Scotland's approach to Learning for Sustainability and Climate Education in educational settings.

While debates about what STEM education means in practice has continued to grow internationally, limited research exists on the professional development of STEM pedagogy and practice in teacher education (Hamilton, 2021). This, as Hamilton (2021) suggests, is because of the continued debate around the nature, pedagogies, and hierarchy of disciplines within STEM education. From this brief overview of the international climate of STEM education, there is a universal demand for STEM education in initial teacher education to support future teachers in their understanding of the purpose and approaches to STEM to carry them out effectively. Given that confidence in STEM teaching and learning significantly influences student engagement, aspiration, and achievement, as well as teacher efficacy and well-being (e.g., Pozo-Rico et al., 2024), it is crucial to explore the role of ITE in bridging the gap between STEM education policies (both international and national) and their practical implementation in the classroom.

1.3 *STEM in Primary Education*

Research shows that early exposure to STEM education, beginning in the early years of formal education and supported by knowledgeable teachers, can significantly strengthen foundational STEM knowledge and cultivate lasting interest and positive attitudes toward STEM (e.g., Nesmith & Cooper, 2019). Students begin making choices about their future in primary school hence it's important that primary preservice and in-service teachers understand the nature and practice of STEM education. While primary teachers play a critical role in STEM implementation (Margot & Kettler, 2019), factors such as the complex knowledge demands, limited class time for STEM, and a lack of accountability (e.g., no reporting requirements) contribute to teachers feeling unprepared to deliver integrated STEM experiences in the primary classroom.

While there is some consensus internationally of the advantages of interdisciplinary STEM tasks in developing generic learning skills and personal dispositions such as communication, critical thinking, creative problem solving, resilience and self-efficacy (Hatisaru et al., 2023), the powerful influence of subject-based, 'high stakes' assessments and reporting, has a major influence on how STEM education is implemented within formal curriculum design. Other research conveys concerns about the importance of maintaining the integrity of individual disciplines ensuring students first build disciplinary understandings within primary settings, before applying discipline-based understandings to integrated STEM contexts (Hourigan et al., 2021). This concern is supported by Hatisaru et al. (2023) advocating that any approach to STEM education (whether subject based or interdisciplinary) should give priority to the mastery of disciplinary knowledge. We contend that ITE should prioritise developing educators' comprehensive understanding of how concepts and skills from each STEM learning area (as outlined in National Curriculum documents) reinforce and enhance one another, which would effectively eliminate this concern.

Further to this, a significant concern internationally, is the unequal representation of disciplines in STEM education with science tending to dominate STEM projects (English, 2017). Despite mathematics being a language that that underpins the other STEM disciplines through logical reasoning, problem-solving, and spatial thinking (Ferme, 2014) it is rarely the focus of STEM activities (English, 2016). Mathematics is arguably the most important component of STEM learning (Easton et al., 2020) and the challenge is for teachers to have the expertise to transfer subject content knowledge and skills, such as those identified in mathematics, into integrated STEM learning experiences (Al-Mutawah et al., 2022) as integrating curriculum is generally complex (Kneen et al., 2020; Venville et al., 2002) and time consuming (Naylor, 2014).

Primary teachers, therefore, need to be supported to develop secure knowledge of the nature and limitation of each subject discipline (in line with how each subject is conceptualised in the curriculum). Hatisaru et al. (2023) therefore advocates for further research into how these perceptions contribute to the ways in which different aspects of STEM curricula and pedagogy are prioritised and explored within teacher education. Using the state of Queensland in Australia as a case study, to address this gap our research question is: *How is STEM education portrayed in the National agenda and primary level education policy and curriculum for both schools and initial teacher education?*

3 Methods

In this study, qualitative document analysis (Bowen, 2009) methods were employed to examine Australian school and ITE curriculum policy documentation to determine how integrated STEM is documented in various jurisdictions and sectors. In recognition of the 'Intent', 'Implementation', 'Impact' framework, which has been the cornerstone of evaluating educational quality in schools (Ofsted, 2023), our study focused on the analysis of policy documentation reflecting the 'intent' of STEM education delivery. This is the first part of the process of effective STEM education enactment. All documentation analysed were in the public domain and was accessed via internet searches during the year of 2023. The following four document categories were selected for analysis relevant for the Australian school and tertiary education sector:

1. Curriculum and education policy documents for schools (including the *Australian Curriculum* (*AC*) (ACARA) and the resources developed to support the curriculum (Scootle documentation, AITSL resources) and statements from the Office of the Chief Scientist
2. Relevant Queensland curriculum authority and jurisdictional websites policies and guidelines (including the Queensland Curriculum and Assessment Authority, Department of Education, Independent Schools Queensland, Catholic Education Queensland)
3. Curriculum/syllabus documentation for tertiary-level initial teacher education programs (including eight Queensland university course outlines/syllabus for 4-year undergraduate Bachelor of Primary Education programs)
4. National accreditation standards of primary ITE programs from the Australian Institute for Teaching and School Leadership (AITSL) website and the extra Queensland College of Teachers accreditation requirements.

Any documentation that did not fit into the above four criteria was excluded from the analysis and not examined. For example, the Australian Academy of Science developed teaching resources and teacher professional development, *reSolve* (https://resolve.edu.au/) for the *AC: Mathematics* and *Primary Connections* (https://primaryconnections.org.au/) and *Science by Doing* https://www.sciencebydoing.edu.au/) for *AC: Science* updated for the latest version of the curriculum (version 9), but while many of these activities include integrated activities they have not been mapped to the other curriculum areas. Once the relevant online documentation was selected based on the above criteria, members of the research team completed separate document analysis of the above texts to identify that nature and extent of alignment with the integration of STEM in education settings. The conceptual framework in Figure 1 was utilised to guide the documentation analysis and discussion of findings.

<insert figure 1 about here>

A content analysis (Krippenhdorff, 2012) was used to make replicable and valid inferences from data in each of the document categories.

1. For the Australian Curriculum we searched for any mention of STEM in *AC: Science, AC: Technologies,* and *AC: Mathematics* and compared the sentences in which STEM was mentioned to identify the intent and similarities and differences between curriculum documents. For the teaching resources to support the *Australian Curriculum F-10* (Scootle documentation, AITSL resources) we searched for those resources that were classified as STEM. We then classified each of the 94 documents retrieved using either a teaching activity, resource, or teacher professional development and then identified the disciplinary content from the curriculum descriptors that are addressed: STEM (for 2 or more of the STEM subjects) or individual disciplines. For statements from the Office of the Chief Scientist we identified where STEM was mentioned and identified the intent of the paragraph.
2. As we are a Queensland based research team and believe that the picture in Queensland is similar to all other Australian states, we chose to analyse Queensland documents by searching jurisdictional websites for any mention of STEM as well as downloading and searching any document that we thought could potentially include STEM. The intent or policy direction of each of these 'STEM' documents was determined. To determine where
3. STEM is taught in primary ITE we analysed each curriculum/syllabus document in each of the 4-year undergraduate Bachelor of Primary Education programs at each of the eight public universities in Queensland that teach ITE to identify where STEM is taught.
4. Finally, we analysed the National accreditation standards for primary ITE programs from the Australian Institute for Teaching and School Leadership (AITSL) website and the extra Queensland College of Teachers accreditation requirements to determine where STEM was mentioned to enable us to document the accreditation requirements.

4 Results

4.1 *The Australian Curriculum*

The Australian Curriculum is specified in two phases: the Foundation -10 (Schooling sector up to and including Year 10) and Senior Secondary (Years 11 and 12). The Foundation -10 curriculum, being considered here, is specified as nine separate learning areas (https://www.australiancurriculum.edu.au/f-10-curriculum/learning-areas/).

At the primary level, STEM is explicitly mentioned in the Rationale of each of Science, Technologies, and Mathematics. The rationale for *AC: Technologies* states that STEM learning requires "explicit teaching of knowledge and skills in each learning area: Science, Technologies and Mathematics." *AC: Science* and *AC: Technologies* describe a transdisciplinary approach to STEM whilst *AC: Mathematics* describes that an interdisciplinary approach, "can enhance students' scientific and mathematical literacy, design and computational thinking, problem-solving and collaboration skills." All three curricula identify the contribution of each to "a diverse and capable science, technology, engineering and mathematics (STEM) workforce." that "supports students to access further study and a variety of careers and jobs" either in STEM or outside of STEM fields

(*AC: Science* and *AC: Technologies AC: Mathematics*). Both *AC: Science* and *AC: Technologies* states that "[d]eveloping STEM competencies enables students to develop, model, analyse and improve solutions to real-world problems." Whilst there are these multiple references to STEM in the Rationale of the curriculum, STEM is not mentioned within the rest of the curriculum documents at the primary level. *AC: Mathematics* has one reference to STEM in the Elaborations for statistical investigations (AC9M7ST03) at Year 7.

4.2 *Teaching resources to support the Australian Curriculum F-10*

A website of resources aligned with the curriculum is provided to support teachers – Scootle (https://www.scootle.edu.au/ec/p/home). These resources were developed and updated for version 8.4 of the curriculum but had not been updated for version 9 when conducting this research but are still available for teachers to use. The documents include both classroom tasks as well as teaching resources (videos and photographs) for classroom use, and teacher professional development. Our analysis classified each of the 94 documents retrieved using a "STEM" search as a teaching activity, resource, or teacher professional development and then identified the disciplinary content: STEM (2 or more of the STEM subjects, as per Vasquez, 2014) or individual disciplines. The results for the number of primary level documents in each category are given in Tables 2 and 3 and show that the largest categories were six technology tasks compared with three integrated STEM tasks (Table 1) and six technology teacher professional development materials compared with four STEM videos (Table 2).

<inset Table 1 about here>

<insert Table 2 about here>

The Australian Institute for Teaching and School Leadership' (AITSL) (https://www.aitsl.edu.au/tools-resources) also provide useful resources on their website with three illustration of practice videos and links to STEM activities for families.

4.3 *The Office of the Chief Scientist*

The previous Australian Chief Scientist, Professor Alan Chubb, expressed frustration with the "small-scale projects, with short-term goals and no recurrent funding. … and too little appreciation is afforded to the demanding task of teaching STEM as it is practiced – as a dynamic and exciting human endeavour." (Australia's Chief Scientist May 2015) in the collaborations between industry and schools. At the release of the *NSSES* Chub (Australia's Chief Scientist, December 2015) he called for support to

> increase STEM teaching quality by lifting the standard of STEM content in ITE as well as improving pathways and in-service support for teachers, sharing that confident, well-prepared STEM teachers are the ones who can inspire students and sustain their natural curiosity in the world around them.

The current Australian Chief Scientist, Dr Finkel, stated that "nothing is more important than mathematics – the language of science. And the fundamentals need to be taught well, because the quality of STEM education is as important as the number of students enrolled." (Australia's Chief Scientist, April 2018, https://www.chiefscientist.gov.au/2018/04/opinion-how-we-can-spread-the-stem-message-in-schools). To achieve this, he argued for

> STEM teachers need to be up-to-date in their knowledge and equipped to teach STEM. If we expect it, we need to resource it: it's that simple. Industry can assist with information on how STEM is being harnessed. But education authorities have to make it a priority and take the lead. (Australia's Chief Scientist, April 2018)

Advocated for STEM teaching in schools Finkel cited that "students need deep discipline knowledge. … a deep understanding for and respect of the social impact of these technologies." (Australasia's Chief Scientist, 14 June, 2018).

4.4 *Queensland curriculum authority and jurisdictional websites primary and junior secondary only*

Considering Queensland as case study, the Queensland Curriculum and Assessment Authority website as well as the policies and guidelines from the websites of each of the three jurisdictions that oversee Queensland schools, the Department of Education, Independent Schools Queensland, and Catholic Education Queensland were analysed. See Table 3.

<insert Table 3 about here>

4.5 *Initial Teacher Education*

Though pockets of good practice exist, such as Real-World Integrated STEM education course offered at Queensland University of Technology, integrated STEM education in primary ITE courses was not consistent. Considering Queensland as a representative example (selected for the authors' geographical location), we explored the course outlines (syllabus) for all courses in the four-year undergraduate Bachelor of Primary Education at the eight major Queensland universities for references to STEM. These eight major Queensland universities demonstrated disparity in preservice teachers' exposure to integrated STEM in teacher preparation. Only two of the eight universities (Queensland University of Technology and University of Queensland) had STEM focused assessments within the primary ITE degree. Two universities (Southern Cross University and University of the Sunshine Coast) had some reference to STEM in course outlines. This variation of offerings demonstrate that many Queensland preservice teachers are unlikely to develop expertise in STEM and STEM integrated teaching and learning during their teacher education as shown in Table 4.

<insert Table 4 about here>

All Australian ITE programs need to indicate how they will satisfy the 37 Australian Professional Standards for Teachers (AITSL, 2022) to be accredited by AITSL and this process is overseen by the Queensland College of Teachers (QCT) which has extra requirements included in Template D. None of the accreditation requirements by AITSL and QCT include any mention of STEM.

5 Discussion

Within each of the three STEM curriculums Science, Technologies, and Mathematics, there is mention of the importance of STEM and the value of using either an interdisciplinary or transdisciplinary approach in the Rationale. However, at the primary level there are no other mentions of STEM within the curriculum documents, including the elaborations that support teachers to implement the curriculum.

While the curriculum aligned resources that support implementation of the Australian Curriculum were not updated for the latest version at the point of analysis, they are still useful. A document analysis of the STEM tasks, only 20% were an integrated STEM (two or more subjects included) whilst 40% were technology only and another 20% were an integrated technology and a non-STEM subject. For the other primary STEM resources and teacher professional development only 22% was STEM whilst 39% was technology only. AITSL provided some useful resources on their website with three illustration of practice videos and links to STEM activities. However, we see a mismatch here between the rhetoric of the Rationale of the individual STEM subject curriculums where STEM is encouraged as part of the reason for learning the individual STEM subjects but there are no explicit examples of integrated STEM activities for teachers to include in their teaching. Also, many of the resources available to support teachers are mislabelled technologies activities. We assert that in the absence of clear policy guidelines mandating the design and implementation of integrated STEM learning experiences—which highlight crucial connections between disciplines and practical applications of subject-specific knowledge and skills—the successful implementation of integrated STEM education will rely entirely on individual teachers' knowledge, skills and confidence.

Australian Chief Scientists have made calls for upskilling both in-service teachers and preservice teachers so that they have both the content knowledge and pedagogical knowledge to inspire students in STEM and be capable of "teaching STEM as it is practiced – as a dynamic and exciting human endeavour." (Australia's Chief scientist, May 2015). The Queensland Government's *A strategy for STEM in Queensland state schools* (State of Queensland Department of Education, 2016) aimed to provide every state school (state government funded school) a specialist STEM teacher and ensured that every state school offered *AC: Digital Technologies*. It is possible that it will be the specialist STEM teacher who is teaching digital technologies, and this may lead to some of the confusion between STEM and Technologies. The QCAA provides a summary of why it is beneficial to teach STEM and provides the link to *National STEM school education strategy 2016–2026* (Education Council, 2015). The other jurisdictional websites generally provide guidance for schools by providing links to useful websites and documents.

Only two universities Queensland University of Technology and University of Queensland provide a dedicated STEM course in their initial teacher education and two others Southern Cross University and University of the Sunshine Coast include STEM within course outlines. This may be that none of the accreditation requirements mandated by AITSL and the QCT mention STEM. This leaves a misalignment between the rhetoric of the need for STEM Education and the reality in initial teacher education and schools.

Teachers are key for integrated STEM education (Wan et al., 2023) and the demand for proficient teachers continues to rise (Tytler, 2020). Universities can play a critical role in the development of both preservice and in-service teachers understanding of interdisciplinary STEM teaching via their ITE offerings, research, and engagement with schools, communities, and partnerships with business and industry. Universities can position themselves at the forefront of educational change, actively shaping the trajectory of STEM pedagogical approaches and curriculum design through their ITE programs and professional development delivered in schools. STEM education is multidisciplinary, and a key strength of universities is access to diverse expertise across disciplines providing valuable insights into how subjects can be integrated to create authentic and meaningful STEM learning experiences for students, whilst addressing mandated curriculum and assessment. Preservice teachers also need support to prepare integrated lesson plans, translating theory into practical application.

Generally, preservice teachers are introduced to the Australian Curriculum (ACARA, 2024) in first year and as they proceed into their second- and third-year subjects, curriculum knowledge increases, opening opportunities to explore interdisciplinary approaches to STEM education. While these opportunities exist, most ITE curricula is discipline based (Wan et al., 2023) aligned to the learning areas of the Australian Curriculum. Teacher educators can collaborate with other teacher educators and academics across disciplines and design curriculum for STEM integrated learning and assessment tasks which include authentic STEM projects (Anderson et al., 2022). As pedagogical experts, teacher educators can use a range of teaching strategies to develop preservice teachers' capacity to navigate knowledge, understanding, and skills across discipline boundaries (Anderson et al., 2022).

Whilst currently there is no national STEM ITE accreditation requirements (AITSL, 2023), which is potentially a barrier, universities can review and evaluate their programs to strengthen integrated STEM learning while meeting ITE accreditation requirements. Universities can redesign ITE programs to offer a STEM specialisation with mapped teaching and assessment which also includes subjects from outside the education discipline. Preservice teachers could experience content that can provide innovative and contemporary STEM contexts, such as first year engineering and technology courses. A dedicated STEM education course could be designed and implemented which explores STEM pedagogies and engages preservice teachers with real community projects. These ITE additions could provide the agency preservice teachers need to lead best-practice STEM education in their future schools.

Universities are positioned to ensure that STEM education content and pedagogies are research-informed and prepare young people for their future. For example, the MindSET-do STEM engagement project at the University of the Sunshine Coast, is a collaboration between universities, schools, teachers, community, business and industry which provides: hands-on career and technical education lessons in schools with Years 4-10; teacher professional development workshops; campus and community events/workshops; and a Uni STEM club designed to support students entering STEM programs and pathways into employment in STEM careers (Author, 2023). The project positively influenced students from as young as Year 6 in their enjoyment, confidence in coding and STEM activities, and intentions to pursue STEM subjects and careers (Author, 2023). MindSET-do provides an interdisciplinary model engaging school students and developing transferable skills of STEM learning, such as critical thinking, creative problem solving, design thinking, and collaborative teamwork, and opportunities for preservice teachers to develop their STEM pedagogy.

Within initial teacher education, traditional representation and forms of STEM content must be challenged, and sustainable STEM practices promoted (Anderson et al., 2022). The STEM Academy at University of Sydney provides ongoing cross-disciplinary STEM professional development to teaching teams from secondary schools. Teachers attend multiple-day workshops where they planned integrated STEM projects to engage and motivate their students. Teachers implemented their projects in their schools and reported back on progress with further time for collaboration and sharing ideas. Teachers valued the opportunity to work in cross-disciplinary teams, share projects across schools, and hear about other schools' successful integrated STEM projects (Anderson et al., 2022).

Whilst the STEM Academy program was for secondary school teachers Anderson et al. (2022), the program could be used with teams of primary school teachers from across year levels in a school. Preservice teachers could be included to contribute ideas and network with teachers and schools in their community to learn about innovative ways teachers and schools work to overcome barriers to integrated STEM education. Examining the key strengths in engagement and partnership opportunities with schools, teachers, community, industry, and business, we can identify the crucial role that universities play in shaping the next generation of educators who are confident to meet the demands of contemporary STEM education.

6 Conclusions

While there is a clear rhetoric advocating for the need for STEM Education, there remains a disconnect with this articulation and teaching and learning in Australian and perhaps other countries' schools. Much of the rhetoric in the Australian Curriculum (ACARA, 2024), jurisdictional websites (e.g., Department of Education, Independent Schools Queensland, Brisbane Catholic Education), board of studies (e.g., QCAA), and the Australia's Chief Scientist refer to the importance of STEM; however, this is not reflected in requirements for national accreditation standards of primary initial teacher education programs (Australian Institute for Teaching and School Leadership [AITSL], 2023). Whilst STEM education is not foregrounded in national ITE accreditation requirements, it is essential that universities address this teacher workforce need. We acknowledge that we have only considered one Australian state and wider analysis provide a better picture of the Australian situation.Our recommendation is for the new *NSSES* policy prioritise the need for primary ITE as a fundamental catalyst for integrated STEM education reflective of real-world STEM (Freeman et al., 2019; Holmes, et al. 2018; Tytler, 2020). Empowering primary school teachers with expertise in STEM education will develop their agency to plan and implement authentic, integrated STEM learning experiences. Underscoring the opportunity ITE and teacher education plays in the efficacy and effectiveness of STEM education, this paper concludes with the following recommendations. Our analysis of exemplary ITE provision for STEM education highlighted the value of partnerships with schools and industries. Further recommendations include ITE being responsive to research, providing opportunities for preservice teachers to develop STEM pedagogies, and opportunities to plan integrated STEM units linked to real community issues.

Future research should re-evaluate the purpose and place of STEM education in primary schools to address the potential misunderstanding that technology is STEM. Research should include ways to support teachers to plan integrated STEM tasks aligned with the scope and sequence of the formal curriculum, that promote greater engagement and application of age-appropriate disciplinary knowledge, underpinned by authentic STEM contexts (e.g., partnerships with industry and local and global issues).

In future studies, it will also be beneficial to identify how subject-specific teacher educators and subject-specific supporting resources model and support STEM pedagogies, enabling preservice teachers to critically bridge theory and practice from the perspective of each STEM subject. Further research is needed to support preservice and in-service teachers with a deep epistemic view of each discipline (the distinctive nature, aims, and values that characterise each subject) and how STEM subjects interact within authentic, real-world contexts. Understanding the value of intentional and formalised STEM learning experiences, with respect to the relationships and interdependencies between discrete subjects, can bring the cross-curricular priorities to the forefront of the Australian curriculum. As identified by Kelchtermans (2019), is a necessary step towards improved STEM pedagogical content knowledge, skills, efficacy, and agency in STEM curriculum design.

These recommendations may require a mindset shift for many teachers (and teacher educators) to design rich and meaningful learning experiences that reflect the real world of STEM, otherwise the discord between STEM education and real-world STEM will remain. This proposal should be supported by research into a STEM learning pedagogical framework embedded within ITE. For example, one in which the rigour, coverage, and balance of each discipline (i.e., both substantive and disciplinary knowledge which frames each subject) is drawn upon within relevant and meaningful contexts. A comprehensive approach to STEM education, where primary educators, recognised as STEM specialists, will not only focus on creating a pipeline for STEM careers starting in early education, but also foster students with the values, knowledge, and skills needed to tackle broader global challenges through formal learning.

STEM education remains an important focus for Australian and global education, and with the *NSSES 2016-2026* policy approaching it's end date, clear direction for ITE innovation in STEM, is essential to assist ITE providers enhance primary ITE programmes and establish opportunities for future STEM education school leaders. Prioritising the research and development of primary ITE STEM education will lead to more skilled and confident teachers with the agency and capacity to design and deliver STEM education reflective of and responsive to the real world of STEM, developing mathematical, scientific, and digital literacy, and promoting problem solving, critical analysis, and creative thinking skills identified in the current *NSSES* strategy.

References

Al-Mutawah, M., Mahmoud, E., Thomas, R., Preji, N. and Alghazo, Y. (2022) Math and Science Integrated Curriculum: Pedagogical Knowledge-Based Education Framework. *Educational Research International*. https://doi.org/10.1155/2022/2984464

Anderson, J., Tytler, R., and Williams, G. (2022). Supporting Curriculum Innovation in Integrated STEM for Secondary Teachers in Australia. *Research in Integrated STEM Education*, *1*(1), 30-59. https://doi.org/10.1163/27726673-00101001

Australian Curriculum Assessment and Reporting Authority [ACARA]. (2024). *Australian Curriculum, Version 9.0*. https://v9.australiancurriculum.edu.au/

Australian Government Department of Education (2023) *Why is STEM important?* National STEM Education Resources Toolkit. https://www.education.gov.au/australian-curriculum/national-stem-education-resources-toolkit/introductory-material-what-stem/why-stem-important

Australian Industry Group (2015) *Progressing STEM skills in Australia.* *https://cdn.aigroup.com.au/Reports/2015/14571_STEM_Skills_Report_Final_-.pdf*

Australian Institute for Teaching and School Leadership (2023). *Understand initial teacher education program accreditation*. https://www.aitsl.edu.au/deliver-ite-programs/understand-ite-program-accreditation

Australia's Chief Scientist (May 2015). *Address to the Australian independent schools stem leadership conference.* https://www.chiefscientist.gov.au/2015/05/speech-address-to-the-australian-independent-schools-stem-leadership-conference

Australia's Chief Scientist (December 2015). *Making STEM a priority in schools*. https://www.chiefscientist.gov.au/2015/12/media-release-making-stem-a-priority-in-schools)

Australia's Chief Scientist (April 2018). *How we can spread the STEM message in schools* https://www.chiefscientist.gov.au/2018/04/opinion-how-we-can-spread-the-stem-message-in-schools

Australia's Chief Scientist (June 2018). *Interview: Australia's Chief Scientist on STEM Partnerships*. https://www.chiefscientist.gov.au/2018/06/interview

Bentley, B., Sieben, R., & Unsworth, P. (2022). STEM Education in Australia: Impediments and Solutions in Achieving a STEM-Ready Workforce. *Education Sciences*, *12*(10), 730. https://doi.org/10.3390/educsci12100730

Blackley, S., & Howell, J. (2015). A STEM Narrative: 15 Years in the Making. *Australian Journal of Teacher Education, 40*(7). http://dx.doi.org/10.14221/ajte.2015v40n7.8

Bowen G.A. (2009) Document analysis as a qualitative research method. *Qualitative Research Journal 9*(2): 27–40.

Bryan, L. A., Moore, T. J., Johnson, C. C. & Roehrig, G. H. (2015). Integrated STEM education. In C. C. Johnson, E. E. Peters-Burton and T. J. Moore (Eds.), *STEM road map: A framework for integrated STEM education* (pp. 23–37). Routledge.

Committee on STEM Education of the National Science and Technology Council (2018). *Charting a Course for Success: America's Strategy for STEM Education*, https://www.whitehouse. gov/wp-content/uploads/2018/12/STEM-Education-Strategic-Plan-2018.pdf

Dare, E.A.; Keratithamkul, K.; Hiwatig, B.M.; Li, F. (2021) Beyond Content: The Role of STEM Disciplines, Real-World Problems, 21st Century Skills, and STEM Careers within Science Teachers' Conceptions of Integrated STEM Education. *Education Sciences, 11*, 737. https://doi.org/10.3390/ educsci11110737

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

Department of Education. (2023) *Strong Beginnings: Report of the Teacher Education Expert Panel*. https://www.education.gov.au/quality-initial-teacher-education-review/resources/strong-beginnings-report-teacher-education-expert-panel

Department of Education (2023) *The Future of Science, Technology, Engineering and Maths (STEM) in Irish Education*. https://opac.oireachtas.ie/Data/Library3/Documents%20Laid/2023/pdf/153doclaid170723_164033.pdf

Easton, G., Wellington, A., Davis, J. P., & Yeh, A. (2020). Foregrounding mathematics in integrated STEM projects via digital technology. *Australian Mathematics*

Education Journal, 2(3), 10–15. https://search.informit.org/doi/10.3316/informit.428614256478827

Erduran, S. (2020) Nature of 'STEM'?: Epistemic Underpinnings of Integrated Science, Technology, Engineering, and Mathematics in Education. *Science and Education*, *29*(4) 781. https://doi.org/10.1007/s11191-020-00150-6

English, L. D. (2016). STEM education K–12: Perspectives on integration. *International Journal of STEM Education, 3*(3). https://doi.org/10.1186/s40594-016-0036-1

English, L.D. (2017). Advancing elementary and middle school STEM education. *International Journal of Science and Mathematics Education, 15* (Suppl 1), 5–24. https://doi.org/10.1007/s10763-017-9802-x

European Schoolnet (2022) *European Integrated STEM Teaching Framework: Executive Summary*. https://steamit.eun.org/executive-summary/

Ferme, E. (2014). What can other areas teach us about numeracy? *The Australian Mathematics Teacher, 70*(4), 28–34. https://search.informit.org/doi/10.3316/informit.906951059161831

Freeman, B., Marginson, S. & Tytler, R. (2019). An international view of STEM education. In *STEM Education 2.0* pp.350 - 363. Brill. https://doi.org/10.1163/9789004405400_019

Grapin, S.E., Haas, A., McCoy, N. & Lee, O. (2023) Justice Centered STEM Education with Multilingual Learners: Conceptual Framework and Initial Inquiry into Pre-Service Teachers' Sense-Making, *Journal of Science Teacher Education, 34*(5), 522-543

Hamilton, M. (2021). An autoethnographic self-study navigating the transition to becoming a stem teacher educator. *The Qualitative Report, 26*(1), 296-315. https://doi.org/10.46743/2160-3715/2021.4462

Hatisaru, V., Fraser, S., & Beswick, K. (2020). 'My picture is about opening up students' minds beyond our school gate!' School principals' perceptions of STEM learning environments. *Journal of Research in STEM Education, 6*(1), 18–38

Hatisaru,V., Falloon,G., Seen, A., Fraser, S., Powling, M. & Beswick, K. (2023): Educational leaders' perceptions of STEM education revealed by their drawings and texts, *International Journal of Mathematical Education in Science and Technology*, https://doi.org//10.1080/0020739X.2023.2170290

Holmes, K., Gore, J., Smith, M., and Lloyd, A. (2018). An integrated analysis of school students' aspirations for STEM careers: Which student and school factors are most predictive? *International Journal of Science and Mathematics Education*, *16*(4), 655–675. https://doi.org/10.1007/s10763-016-9793-z

Honey, M., Pearson, G. & Schweingruber (Eds.). (2014). *STEM integration in K-12 education: Status, prospects, and an agenda for research*. National Academies Press. https://www.middleweb.com/wp-content/uploads/2015/01/STEM-Integration-in-K12-Education.pdf

Hourigan, M., Dwyer, A.O., Leavy, A.M. & Corry, E. (2021) Integrated STEM – a step too far. *Irish Educational Studies, 41*(2):1-25.

Kelchtermans, G. (2019). Early career teachers and their need for support: Thinking again. In A. Sullivan, B. Johnson, and M. Simons (Eds.), *Attracting and keeping the best teachers: Issues and opportunities* (pp. 83–98). Springer.

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

Kneen, J., Breeze, T., Davies-Barnes, S., John, V., & Thayer, E. (2020). Curriculum integration: The challenges for primary and secondary schools in developing a new curriculum in the expressive arts. *Curriculum Journal, 31*(2), 258–275. https://doi.org/10.1002/curj.34

Krippendorff, K. (2012) Content Analysis: An introduction to its Methodology. Third Edition. London: Sage Publications.

Kurup, P.M., Li, X., Powell, G. and Brown, M. (2019) Building future primary teachers' capacity in STEM: based on a platform of beliefs, understandings and intentions. *International Journal of STEM Education 6*, 10. https://doi.org/10.1186/s40594-019-0164-5

Li, Y. (2014) *International Journal of STEM Education* - a platform to promote STEM education and research worldwide. *International Journal of STEM Education 1*, 1. https://doi.org/10.1186/2196-7822-1-1

Margot, K.C.& Kettler, T. (2019) Teachers' perception of STEM integration and education: a systematic literature review. *International Journal of STEM Education 6*, 2. https://doi.org/10.1186/s40594-018-0151-2

McMaster, N., Carey, M., Martin, D., & Martin, J. (2023). Raising Primary School Boys' and Girls' Awareness and Interest in STEM-Related Activities, Subjects, and Careers: An Exploratory Case Study. *Journal of New Approaches in Educational Research*, *12*(1), 1-18. https://doi.org/10.7821/naer.2023.1.1135

Moore, T. J., & Smith, K. A. (2014). Advancing the state of the art of STEM *Integration. Journal of STEM Education, 15*(1), 5-10.

National Science and Technology Council (2024) *Federal Strategic Plan for Advancing STEM Education and Cultivating STEM Talent*. https://www.whitehouse.gov/wp-content/uploads/2024/11/2024fedSTEMplan.pdf

Naylor, J. (2014). *Enacting Australian Curriculum: Making connections for quality learning–An issues paper prepared for the Queensland Studies Authority*. www.qcaa.qld.edu.au/downloads/p_10/ac_enact_ac_paper.pdf

Nesmith S.M.& Cooper. S. (2019) Engineering process as a focus: STEM professional development with elementary STEM-focused professional development schools. *School Science and Mathematics, 119*, 487–498. https://doi.org/10.1111/ssm.12376

OECD (2024), *Bridging Talent Shortages in Tech: Skills-first Hiring, Micro-credentials and Inclusive Outreach, Getting Skills Right*, OECD Publishing, https://doi.org/10.1787/f35da44f-en.

Office of the Chief Scientist. (2023, February 6). *Starting the school year right: Why STEM needs to be front of mind across the education system*. Media Release. https://www.chiefscientist.gov.au/news-and-media/starting-school-year-right-why-stem-needs-be-front-mind-across-education-system

Ofsted (2023). *School inspection handbook*. Crown Copyright.

Pozo-Rico, T., Scott, R., Bak, M., Castejon, J.L., & Gilar-Corbi, R. (2024) Riding the wave towards flourishing in STEM education: Enhancing teaching efficacy through a K-12 training program, *Teaching and Teacher Education*, *143*.

Prinsley, R. & Johnston, E. (2015) *Transforming STEM teaching in Australian primary schools: everybody's business*. Office of the Chief Scientist.

Queensland Curriculum and Assessment Authority (2017). *STEM in Queensland* schools. https://www.qcaa.qld.edu.au/downloads/aciq/stem-resources/teaching/ac_stem_qld_schools.pdf

Scottish Government. (2022). *STEM education and training strategy - refresh: Second annual report and third/fourth year delivery plan*. Retrieved January 8, 2025, from https://www.gov.scot/publications/stem-education-training-strategy-refresh/pages/5/

Shaughnessy, M. (2013). Mathematics in a STEM context. *Mathematics Teaching in the Middle School, 18*(6), 324.

State of Queensland Department of Education, (2016). *A strategy for STEM in Queensland state schools* Schools of the future STEM strategy for Queensland state schools

State of Queensland Department of Education (2019). *Review of STEM education in Queensland state schools 2015 – 2017. Final Report*. Queensland, Australia.

Strimel, G., & Grubbs, M. E. (2016). Positioning technology and engineering education as a key force in STEM education. *Journal of Technology Education*, *27*(2), 21–36.

Timms, M. J., Moyle, K., Weldon, P. R., & Mitchell, P. (2018*). Challenges in STEM learning in Australian schools: Literature and policy review.* Australian Council for Educational Research (ACER). https://research.acer.edu.au/policy_analysis_misc/28

Tytler, R. (2020). STEM Education for the Twenty-First Century. In: Anderson, J., Li, Y. (eds) *Integrated Approaches to STEM Education. Advances in STEM Education*. Springer.

UK Government. (2023). *The UK science and technology framework. Department for Science, Innovation and Technology*. Retrieved January 8, 2025, from https://www.gov.uk/government/publications/uk-science-and-technology-framework/the-uk-science-and-technology-framework

Vasquez, J.A. (2014). STEM-Beyond the acronym. *Educational Leadership 72*(4), 10-15.

Venville, G. & Wallace, J. & Rennie, L. (2002) Curriculum Integration: Eroding the High Grounds of Science as a School Subject? *Studies in Science Education. 37*. 43-83.