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Article

Understanding Secondary Inservice Teachers' Perceptions and Practices of Implementing Integrated STEM Education

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Abstract: Integrated STEM (i-STEM) education is attracting attention from educators and researchers worldwide to improve student achievement and engagement in STEM subjects and encourage the take-up of STEM-related careers. Multiple models of STEM integration have been proposed, and how i-STEM is interpreted and enacted in school contexts appears to vary considerably. This article reports the perceptions and practices of a group of Australian secondary school teachers with a commitment to implementing i-STEM in their schools but who have not received any specific professional development in this domain. Through individual, qualitative interviews, the study revealed considerable variation in how the teachers interpreted and enacted i-STEM in their schools. Teachers tended to develop learning activities that prioritized the subject area of their particular expertise and that had only tenuous links to mathematics. They considered i-STEM more engaging for their students than traditional subjects but were constrained in their planning by their various school regimes concerning assessment, curricula, and timetables. These structural and systemic impediments represent a core challenge for STEM teachers and teaching as greater numbers of schools and teachers in Australia are expected to implement some form of i-STEM education. Insights from this study point to the importance of developing support structures that allow for variations in context, as well as teacher interest and experience, yet that embrace a coherent and cohesive view of i-STEM, in the absence of a formal STEM curriculum and available professional development opportunities.

Keywords: integrated STEM; STEM curriculum; secondary education; in-service teachers; professional development

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1. Introduction

Broadly speaking, the goals and purposes for Science, Technology, Engineering, and Mathematics (STEM) education derive from two main agendas. One agenda is political, prioritizing economic and vocational goals, while the other is educational, emphasizing goals that pertain to student learning, particularly in science and mathematics, and what students need to know and be able to do as citizens in the 21st century (Blackley & Howell, 2015; Lowrie et al., 2017; Sanders, 2008; Timms et al., 2018). In the past decade in Australian schools, the political agenda has been a predominant force driving STEM education (Marginson et al., 2013). According to this agenda, the goal of STEM education is to encourage more students (particularly girls) to pursue post-secondary school studies in STEM disciplines, thereby increasing the STEM workforce and so contributing to national prosperity (Blackley & Howell, 2015; Office of the Chief Scientist, 2020). These goals are embedded in the Australian Education Council (2015) national strategy document: "ensure all students finish school with strong foundational knowledge in STEM and related skills" and "ensure that students are inspired to take on more challenging STEM subjects" (p. 5).

In contrast, when viewed from an educational agenda, the goals of STEM education shift from their vocational nature to focus on students' learning and engagement. Through this educational lens, STEM education is interpreted as involving the integration of the STEM disciplines through real-world contexts (Blackley & Howell, 2015; Moore et al., 2020). Typically referred to as integrated STEM or i-STEM, such a view emphasizes three important considerations. First, students need to learn about and appreciate the disciplinary characteristics and knowledge of each constituent of STEM. Second, students need to develop particular skills (often referred to as STEM skills or 21st century skills), such as problem solving, critical thinking, collaboration, and creative thinking. Third, the application of such disciplinary understanding and skills by students needs to be situated in authentic contexts, such as exploring real-world problems or issues, which students can relate to in their everyday lives (Blackley & Howell, 2015; Moore et al., 2020; Australian Curriculum Assessment and Reporting Authority, 2016; Honey et al., 2014; Rennie et al., 2018).

Research suggests that while teachers recognize the potential for i-STEM to offer learning opportunities that are more engaging than the traditional STEM disciplines and that develop students' skills and knowledge relevant to their everyday and future lives (El-Deghaidy et al., 2017; Lesseig et al., 2016; Maeng et al., 2017; Xu et al., 2023), knowledge of what i-STEM actually looks like in practice and how to implement i-STEM in schools appears limited. For instance, when teachers have poor disciplinary knowledge and limited pedagogical practices in science and mathematics, students may not find these subjects engaging nor be able to see connections to their lives (Lyons, 2006; Tytler et al., 2008). Additionally, most teachers have completed teacher education courses focusing on one or two STEM disciplines, rather than focusing on disciplinary integration (Hynes et al., 2017; Shah et al., 2020). Similarly, some teachers lack the confidence or knowledge about engineering and design to teach i-STEM (El-Deghaidy et al., 2017; Lesseig et al., 2016; Srikoom et al., 2017). For many practicing teachers, planning for and teaching i-STEM will require them to develop their knowledge and practice in new ways that align with the previously identified goals of STEM education. That is, they will need to develop disciplinary knowledge within the different STEM disciplines, along with pedagogical content knowledge that enables them to implement meaningful learning experiences that integrate discipline knowledge with skill development, and within authentic contexts (Timms et al., 2018; Moore & Smith, 2014).

While there are various research-based claims about what comprises i-STEM and what it *might* look like in practice, there is limited empirical evidence about practicing teachers' actual perceptions and experiences of i- STEM (Wang et al., 2011). There is even less evidence about the perceptions and practices of teachers who have not experienced any professional development (PD) nor formal preparation in i-STEM. That is, these claims can act as hypotheses and provide useful theoretical perspectives. However, to support i-STEM teachers in appropriate, practical, and effective ways, it is important to understand how these teachers conceptualize, plan for, and teach i-STEM. Given the strong emphasis on implementing i-STEM in schools and in the absence of a formal i-STEM curriculum to guide teachers' thinking and practice, this study aims to shed light on a particular group that has been thus far neglected in the literature. Hence, this study, which is situated within an Australian context, explores this focus through the following two research questions: How do teachers in secondary schools without any formal preparation in STEM integration think about implementing i-STEM within their schools and classrooms? And what issues and challenges do these teachers encounter in both designing and implementing teaching programs that integrate the STEM disciplines?

Our study is intended to inform the developing literature on i-STEM education from an in-service secondary teacher perspective. Although there is an emerging body of literature investigating the impact of various formal PD programs on teachers' understanding and enactment of i-STEM, there is a need to explore how teachers conceptualize i-STEM and what teachers report they actually do in their schools and classrooms, outside of the influence of formal PD. Hence, our study aims to uncover valuable insights into the real-world practices, challenges, and informal learning strategies of this group. Their perspectives can shape a more nuanced approach to teacher support and development in STEM education through informing curriculum, professional learning, and policy initiatives.

2. Literature Review

2.1. Integrated STEM Education

Various researchers have offered their views on how i-STEM is defined and what it should look like in practice. Widely cited is the view of Moore et al. (2014), who propose that "integrated STEM education is an effort to combine some or all of the four disciplines of science, technology, engineering, and mathematics into one class, unit, or lesson that is based on connections between the subjects and real-world problems" (p. 38). While others express similar views (Sanders, 2008; Timms et al., 2018; El-Deghaidy et al., 2017), the description above is flexible and does not preclude the inclusion of additional disciplinary areas. Other researchers integrate STEM disciplines with the arts (often represented as 'STEAM') to further benefit student learning and interest (Charette, 2015). However, we do note the argument against this form of integration from Lyons (2018), who asserts that mathematics is central to "the STEM construct" (p. 40) but not to the arts.

Some researchers have taken a different approach to understand and conceptualize i-STEM education. For example, Nadelson and Seifert (2013, 2017) view STEM education as forming a continuum, with one end representing individual STEM disciplines being taught separately in highly structured programs that emphasize disciplinary content knowledge and lower-order thinking skills. This type of approach is often referred to as a disciplinary approach to STEM education. The other end of the continuum represents the full integration of these disciplines, where students encounter open-ended problems that involve a proficiency in STEM knowledge and skills, which promotes higher-order thinking, and is often referred to as a transdisciplinary approach to STEM education (Corrigan, 2020).

Larkin and Lowrie (2023) used this notion of a continuum to form the basis of their systematic literature review of STEM integration in primary school settings. They identified that most teachers (55 out of 60 peer-reviewed journal articles) did not teach in ways that aligned with interdisciplinary or transdisciplinary approaches. Larkin and Lowrie (2023) created two additional "less integrative categories" (p. 26) to take into account numerous studies in STEM education that, in their analysis, did not meet the threshold of the lowest level of integration. They concluded by calling for increased support for teachers to teach STEM in integrated ways, as it "is envisaged and promoted" (Larkin & Lowrie, 2023, p. 31), rather than the minimal levels of integration that are currently occurring.

In contrast, Rennie et al. (2018) avoid the use of a continuum model that appears to privilege some forms of thinking and acting over others and instead propose that STEM integration involves six categories: "synchronised, thematic, project-based, cross-curricular, school specialised, and community-focused programs" (pp. 95–96). According to Rennie et al. (2018), these categories offer a more diverse range of integration approaches that consider both the individual curriculum and the school context.

Based on a comprehensive review of i-STEM education research and program evaluation reports, Honey et al. (2014) produced a descriptive framework consisting of four high-level features of i-STEM education to help "make sense of this confusing landscape" (p. 2) of defining i-STEM. These include (i) goals for students and educators, (ii) outcomes for students and educators, (iii) nature and scope of integration, and (iv) implementation. Each feature has specific subcomponents, as illustrated in Figure 1.

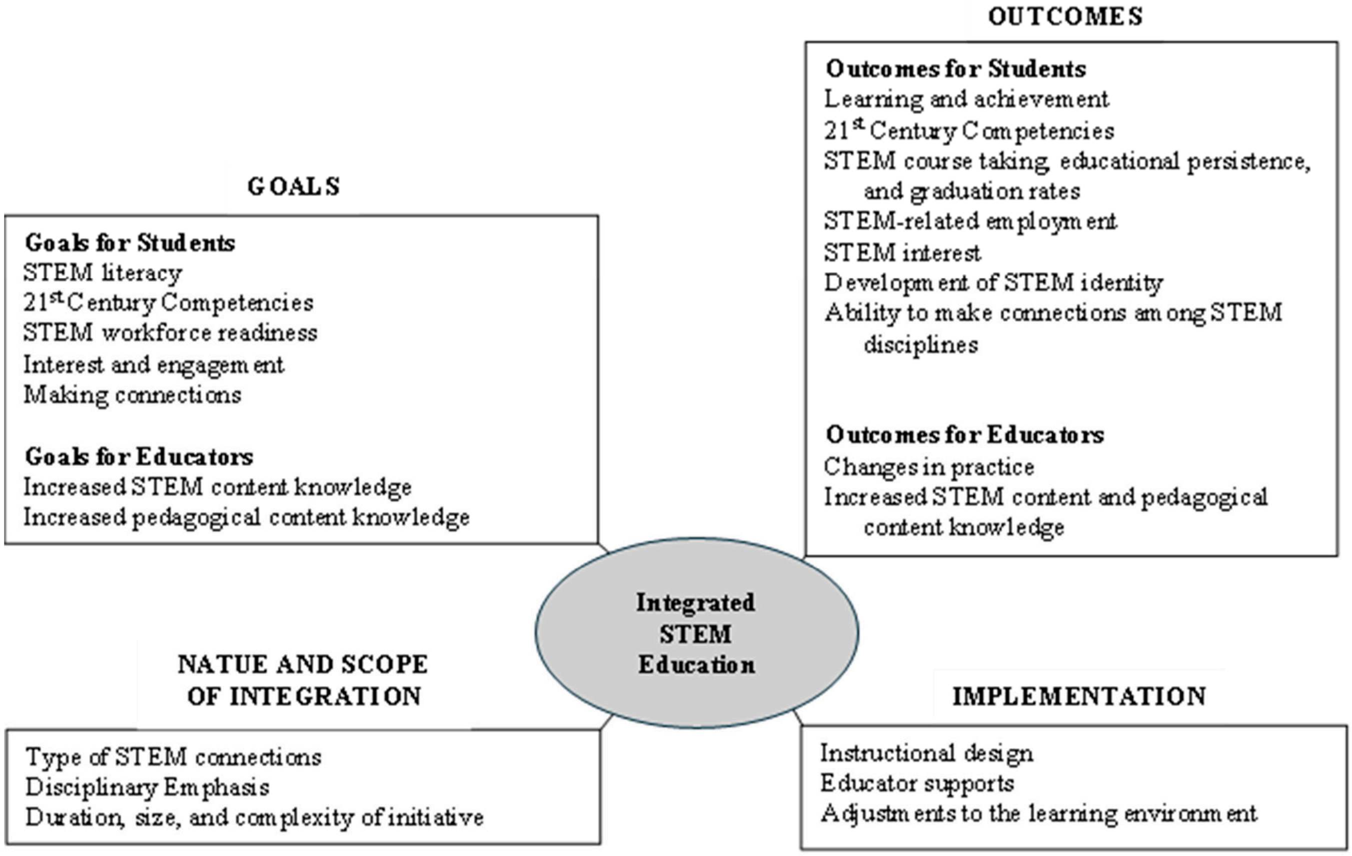

Figure 1. Descriptive framework of general features and subcomponents of integrated STEM education (Honey et al., 2014, p. 32).

The purpose of the Honey et al. (2014) framework was to identify "a small number of salient features" (p. 47) of i-STEM education that might encourage the use of a common language amongst different stakeholders. Features and subcomponents are considered "illustrative" rather than "comprehensive" (p. 44), as other factors may be appropriate to consider in relation to designing and implementing i-STEM education. In the present study, this framework provides an operational definition on i-STEM, and it is used as both a conceptual and analytic tool to examine how the participating secondary teachers conceptualized, planned for, and enacted integrated STEM education in their schools.

2.2. Planning for and Teaching Integrated STEM

The context for i-STEM education can vary greatly between schools and even classrooms within the same schools. For instance, some i-STEM learning experiences may involve one or more teachers or classes and require different lengths of time to complete. Such experiences may be place-based integrated, involving schools and STEM professionals in the local community (Honey et al., 2014; Nadelson & Seifert, 2013). Similarly, schools may develop partnerships with STEM professionals that can lead to new ways of working together (Tytler et al., 2018). Additionally, some i-STEM experiences may take the form of school clubs, competitions, and holiday programs and/or be organized by STEM professionals away from school sites with little input from teachers (Lowrie et al., 2017).

When planning for i-STEM education, two commonly described approaches are content integration and context integration. In content integration, lessons or units of work include learning goals from content in multiple disciplines. For example, the approach may be to integrate "engineering thinking with mathematics and/or science content where learning multiple areas including engineering are part of the learning objectives for the activity or unit" (Moore & Smith, 2014, p. 5). In contrast, context integration involves learning content in one discipline and using the contexts from other disciplines to provide relevance (Moore et al., 2014). Both approaches share a common feature of a focus on real-world problems, where the context is purposefully chosen to have social and cultural relevance to the student.

2.3. Challenges Associated with Integrated STEM

Corrigan (2020) describes three broad levels of challenge in teaching i-STEM: policy, school, and teacher. The challenges of i-STEM at a policy level are concerned with how governmental priorities and curriculum structures support i-STEM. As Corrigan (2020) points out, to enhance i-STEM there must be "intrinsic educational value" (p. 11); however, many countries do not embrace that notion through their policies and guidelines for schools. In the Australian context for example, governmental resources exist to provide teachers with guidance around i-STEM (Australian Curriculum Assessment and Reporting Authority, 2016; Department of Education and Training, 2022); however, the curriculum is structured in a disciplinary way, with engineering subsumed into technology (Victorian Curriculum and Assessment Authority [VCAA], n.d.). This presents a challenge to schools and teachers to interpret i-STEM and to plan and teach accordingly.

School level challenges focus on how school leaders effectively see, and utilize, integration across the curriculum. While the school-level challenge is centered on interpreting the curriculum, there are also pragmatic challenges, such as how the school supports teachers to plan and teach i-STEM, including providing appropriate time for planning, along with promoting collaboration between teachers. Xu et al. (2023) highlight the need for a shared vision for i-STEM education within a school that is supported by school leaders, as this will mitigate some of the challenges faced at this level.

Teacher-level challenges focus on teacher knowledge, capabilities, and self-efficacy, as signaled earlier. For example, do teachers have adequate content knowledge for the different disciplines and appropriate pedagogical content knowledge to be able to teach STEM concepts? Are teachers able to plan and teach in an integrated way? Additionally, teachers' knowledge and confidence will impact the planning and teaching processes, particularly as many teachers find it challenging to understand and integrate aspects of engineering (El-Deghaidy et al., 2017; Lesseig et al., 2016; Srikoom et al., 2017; Ellis & William, 2020).

2.4. STEM Education in the Australian Context

Within the international research literature, it has been noted that Australia has been "relatively slow" (Ellis & William, 2020, p. 439) to adopt STEM education. The impetus to build momentum in Australian school-based STEM education was initiated through key publications from The Office of the Chief Scientist (2013, 2014) and the Australian Industry Group (2015) that emphasized the importance of improving Australia's STEM education "for Australians to effectively manage the changing environment, their health and wellbeing, their food, water and energy, their security, and their economy" (Murphy et al., 2019, p. 123). Further impetus came from increasing governmental concern about the relatively poor performance of Australian students in international comparative tests of science and mathematics (Freeman et al., 2019) and the low numbers of students (particularly girls and students from low socioeconomic groups) choosing to study STEM subjects beyond compulsory levels of schooling (Goodrum et al., 2012; Kennedy et al., 2014).

To address these issues, the National STEM School Education Strategy (2016–2026) was produced by the Australian Education Council (2015) with the aim to enhance students'

STEM competencies and ambitions, which was quickly followed by the different Australian states and territories producing their own STEM education strategies. Murphy et al. (2019) conducted an analysis of these different strategies, and their findings highlighted a consistently strong emphasis on an economic/political agenda with "the strongest emphasis ... on facilitating career pathways when exiting school" (p. 134). Their analysis also noted considerable variation amongst the strategies, in particular, a lack of consensus "as to whether STEM education should be delivered through the discrete disciplines, or as a learning experience where the disciplines are integrated, with the strategies variously describing 'STEM' as being four individual disciplines, cross-disciplinary, and/or inter-disciplinary" (p. 32).

Despite the vagueness associated with defining the goals and practices of i-STEM education in Australia and its absence within the national curriculum, there has been a great deal of enthusiasm by teachers and schools for i-STEM education (Timms et al., 2018) Partly, this enthusiasm has been fueled by the availability of considerable government and private funding for STEM initiatives across all levels of education and partly through the efforts of schools to become attractive to potential students by offering some form of STEM education. It is within this context of teacher interest and school uptake, where teachers have not received formal professional development, that the present study took place.

3. Materials and Methods

3.1. Context and Participants

Secondary school teachers (n = 11) from Victoria, Australia, with a commitment to teaching i-STEM to junior/middle school students (Years 7–10) were recruited to take part in this study. This included teachers who may not have a background in one of the STEM disciplines but who expressed interest in teaching i-STEM in their school. University ethics approval was obtained (Project #171184), along with approval from the participating school sectors (Catholic, Independent, and Government). Participants were recruited based on recommendations from sector representatives who were knowledgeable about the STEM teachers working in their schools. After disseminating information about the study to the suggested participants and schools, 11 teachers volunteered and consented to taking part from nine schools. All teachers in this study teach i-STEM in their schools. Table 1 below shows the names (pseudonyms) of the participating teachers, along with their disciplinary training and type of school. Note that two teachers, Tania and Jane, requested to be interviewed together due to their availability. Both participants had the opportunity to fully engage and respond to questions, and their data were treated individually.

Table 1. Participant names (pseudonyms), disciplinary training, and type of school.

Name	Disciplinary Training	Type of School
Fiona	Mathematics, science, and religious education	Catholic Secondary (boys)
Donna	Food technology	Catholic Secondary (co-ed)
Denise	Science and psychology	Catholic Secondary (girls)
Sam [1]	Visual art, design, and technology	Catholic Secondary (girls)
Nicole [1]	Art and primary school qualification	Catholic Secondary (girls)
Rohan	Engineering	Independent K-12 School (co-ed)
Gary	Engineering	Independent K-12 School (co-ed)
Kay	Chemistry and science	Independent Secondary Alternative School (co-ed)
Cate	Science and mathematics	Independent Secondary School (girls)
Tania [2]	Science	Select Entry Government Senior Secondary School (co-ed)
Jane [2]	Science	Select Entry Government Senior Secondary School (co-ed)

[1] Teachers from the same school that were interviewed separately. [2] Teachers from the same school that requested to be interviewed together.

3.2. Research Design, Data Collection, and Data Analysis

Underpinning this study was an interpretive methodology, as the aim was to make interpretations about the participants' perceptions and self-reported practices when implementing i-STEM in their schools. We define perceptions in terms of how teachers' view and understand i-STEM education, including their ideas about its importance, relevance, and how it should be implemented in the classroom. We define practices in terms of what they self-report they actually do when teaching i-STEM. Qualitative data were deemed as the most appropriate data to collect due to this theoretical stance and the research aims. Data were collected using a semi-structured individual interview, conducted by the third author, which was audio recorded and lasted between 45 and 60 min. This flexible approach allowed participants to share detailed information about their thinking and espoused practices, and the interviewer could seek additional clarification or explore responses further, as needed. The guiding questions for the interview were developed in light of the key themes presented in the literature review and our research questions, and they focused on understanding participants' views of i-STEM and what it looked like in their school; what influenced their planning processes; how they planned to integrate the different disciplines; their teaching approaches; what a typical i-STEM lesson may look like; and some challenges that exist when implementing i-STEM (see Appendix A for these guiding questions).

All audio-recorded interview data were transcribed verbatim and analyzed using a deductive thematic analysis (Braun & Clarke, 2006), guided by the descriptive framework for i-STEM (see Figure 1). The focus of this analysis was understanding how the participating teachers conceptualized i-STEM, including why it was important for them and their school; how they planned to teach i-STEM, what happened during the enactment of their plans; and the issues and challenges they faced when planning and teaching i-STEM. Data were initially analyzed independently by the first two authors, who then compared themes to ensure inter-rater reliability and establish trustworthiness. Agreed upon themes were discussed with the third author for confirmation. Once confirmed, data were recoded and re-analyzed by the first two authors independently and then combined. In addition to being guided by the framework from Honey et al. (2014), this approach to analyzing the data allowed for comparisons to the continuum of STEM integration from Nadelson and Seifert (2013, 2017), while also considering the challenges raised by Corrigan (2020).

4. Findings

The findings from this study are presented below within the categories from the Honey et al. (2014) framework that was used as a conceptual and analytical framework. The categories are further organized according to the themes identified in Section 3.2 above. The order in which the themes are presented is broadly based on the frequency with which they occurred. Appendix B shows a summary of the categories and themes, to highlight their frequency.

4.1. Goals and Outcomes of i-STEM Education

Five key themes emerged when analyzing the participants' data concerning their ideas about the goals and outcomes of i-STEM education: 21st century skills and competencies, interest and engagement, preparation for future STEM course taking, goals and outcomes for i-STEM educators, and perceptions of parents and colleagues. While goals and outcomes were presented by Honey et al. (2014) as two separate features of i-STEM, they have been amalgamated here due to how participants talked about these aspects in synonymous ways.

4.1.1. 21st Century Skills and Competencies

All but one participant (91%) identified the development of 21st century skills and competencies as an important goal or outcome of i-STEM education. Participants focused on students acquiring broad skills, such as "thinking skills" or "collaboration" that can be applied beyond individual subject areas or schoolwork to everyday life situations. For example, Denise explained,

> My ultimate goal is to get students coming out of school as great thinkers that do not think within the confines of a subject area but employ widespread thinking skills to solve problems in life.

Cate emphasized that i-STEM classes provided more opportunities to develop these skills without the constraints of traditional individual subject areas, such as science:

> . . . the collaboration and the creative thinking and the critical thinking can be really hard to generate in a standard science lesson on its own. So often, because of safety reasons, students will have to follow practical instructions rather than problem solve through practical [activities] themselves. . . I think STEM gives us greater freedom to really develop those soft skills.

Sam identified that his students collaborated in ways that mimicked a work environment during i-STEM classes, helping them to develop skills that would be important post-school:

> They [students] are kind of essentially almost working in teams as you would in employment. . . So, they were teaching themselves skills which essentially, I think I would call them 21st century soft skills, entrepreneurial skills, they are really skills that sort of have a value on the job market.

4.1.2. Interest and Engagement

Seven of the eleven participants (64%) identified improving student interest and engagement in STEM subjects as a central goal for i-STEM. Several compared student experiences within i-STEM to traditional classroom settings and described how students found i-STEM learning opportunities more interesting and engaging. For example, Gary learned from his students that the way teachers taught science and mathematics at his school was "really boring", especially for girls, so his aim was to address this deficiency:

> . . .to engage kids in science and mathematics so that they do not think it's boring, which was what I was being told by my year nine students, particularly girls. They were not engaged, and they thought it was all a waste of time and from my background, engineering and science, I just could not understand why that would be.

Like Gary, other participants talked about how their own backgrounds and views shaped their ideas about i-STEM as an engaging context for learning. For example, through her background in zoology, Denise created connections with a local zoo and used that to create motivating i-STEM learning opportunities for her students. Fiona argued that students' engagement significantly increased with i-STEM opportunities compared with traditional ways of teaching science. She identified that she can "teach forces on the PowerPoint" but notices that "kids' eyes glaze over, and they don't care". In comparison, in i-STEM classes, "the buzz in the classroom is exciting [from] the energy in the classroom that the kids bring".

4.1.3. Preparation for Future STEM Course Taking

Four of the eleven participants (36%) linked the goals of their i-STEM program to supporting students' future learning in STEM subjects. For example, Tania explained that her highly academic senior secondary school was oriented towards preparing students for success in high-stakes testing in their final year of schooling. She explained that "they [students] are all going to be doctors or engineers. Some subsets of them are going to do bio-med [icine] with a commerce side order. That is the sort of kid that we're catering to". Therefore, Tania's i-STEM classes were oriented towards promoting links between science, mathematics, and technology that may be useful for students' future studies. Similarly, Rohan sought to develop an i-STEM curriculum that aligned with learning in the senior classes, as he was conscious of tensions between learning in i-STEM classes and the requirements of high-stakes senior assessment. However, he also explained the need to balance achieving high test scores with producing a "wholesome person when they [students] move out of school." In a similar vein, Nicole considered how her i-STEM program supported students as they progressed to high-stakes testing; however, she was less concerned with the development of their content knowledge per se, instead aiming to develop students' familiarity with and understanding of the processes and language of the STEM disciplines:

> My idea of . . . introducing this [i-STEM] into year seven and by the time they get to VCE [final years of schooling], that they're completely familiarized with that language used such as 'prototyping' and 'research' and why they're researching and 'concept designs' and then trying them out with your prototyping and finding out what doesn't work right and problem-solving skills throughout that process.

In a different approach, Donna, a passionate advocate of i-STEM, started a lunchtime i-STEM club to try to attract middle school students, with the aim to increase STEM subject taking at the senior level.

Three participants (27%) also talked about a goal of i-STEM as increasing the school profile within the community as a "STEM school". For Rohan, this was an explicit directive from school management to attract new students, as the school was competing for students in the local area. This led to his focus on robotics, since it was unique to the school and innovative.

4.1.4. Goals and Outcomes for i-STEM Educators

Six of the eleven participants (55%) identified the development of their own knowledge, including content knowledge, pedagogical knowledge, and pedagogical content knowledge, as important requirements for, and outcomes of, teaching i-STEM.

For instance, Fiona explained that while you "should have a background, some sort of background in science, math, and technology", i-STEM teachers needed to "be willing to try new things and learn new things if needed", which she contextualized with her own learning of designing processes in technology. Oftentimes, these requirements and outcomes emerged as teachers engaged in their i-STEM teaching—for example, the need to develop the confidence to relinquish classroom control and become an adaptable practitioner, which can require learning new specialized skills. As Cate explained,

> With [integrated] STEM you do have to step back and go, "I'm not in control of what the final product is going to look like" . . . I can only control it up to this point, they're going to come up with their own ideas and I actually have to let them run with it. In that process you learn lots of things, you know, like the 3D program that we use, we may not use that one next time or we might use one that gives them greater flexibility than what that particular program did.

Other teachers also talked about changes in their instructional practices. For example, Nicole described how the flexibility and openness of the i-STEM curriculum at her school had strengthened her pedagogy and enabled her to be more responsive to her students, compared with the pre-structured curriculum of traditional subjects:

> [Teaching i-STEM], it's about knowing your students and knowing what they need out of learning, and how they work best in the situation that they're given. That strengthened that part of my pedagogy... rather than listening to the curriculum, it's more about what the student actually is showing you in front of you.

According to Nicole, these outcomes were augmented by working collaboratively:

> I really realized the value in working with other people... I probably wouldn't be able to do [i-STEM] on my own, because I don't have a background in science. If you're working in a team of people who have particular different strengths in different subjects, it just strengthens the whole program.

Relatedly, three participants (27%) expressed a need for further professional development for themselves and their colleagues, while also highlighting some challenges. Donna argued that professional development should focus on "building their [teachers'] confidence [for teaching i-STEM]", as she felt that "there's some struggles with it [confidence]". Rohan expressed that "professional development is one of the challenges" but did not elaborate further, except for outlining the difficulty his school faced when seeking to recruit qualified STEM teachers.

4.1.5. Parent and Colleague Perceptions

The goals and outcomes identified by 5 of the 11 participants (45%) for their school's i-STEM curriculum did not always align with expectations from parents or even other colleagues. For example, Rohan explained the challenge of "getting the parents to understand that we are not wasting time playing games in the classroom. There's learning taking place". To support this shift, he encouraged parents to get involved in STEM projects at his school and had experienced considerable success, to the extent that "they [parents] would rather their child be doing some of the robotics projects rather than sitting in maths class".

Similarly, Sam expressed concerns that parents at his school do not take their students' i-STEM learning seriously or even care to understand what i-STEM entails: "students will say 'my parents want me to do well in English and maths and maybe science ... so, it [i-STEM] doesn't really matter'". This situation created pressure for Sam regarding the curriculum time that could be allocated to i-STEM: "How much of your precious class time can you devote to learning another learning area, if the students at the end of the day have just done science as far as their parents are aware?"

These kinds of concerns were also echoed in the ways that participants described their colleagues' views of i-STEM. For example, Cate talked about some of her science-teaching colleagues describing i-STEM as "wasted time even thinking about it or trying to do it". They did not want to include i-STEM in their regular science teaching and saw no reason to change their current teaching practices, because "we've always done science this way, and we don't think it should change". Fiona explained that "getting teachers on board" with i-STEM is a significant challenge at her school, including a mathematics teaching colleague who explicitly said to her, "STEM is a waste of time. There is no career path [for students] in this." When confronted with similar views from colleagues, Denise took a different approach and introduced students to i-STEM via an informal lunchtime club to build interest and momentum with students to introduce i-STEM into the curriculum, rather than starting with the teachers.

In summary, participants shared similar views regarding the purpose of i-STEM, espousing how this approach supported skill development while promoting interest and engagement in STEM subjects, which would help students with future studies. Similarly, many participants recognized that teachers would need to develop content and pedagogical knowledge to teach STEM in an integrated way, including changing and adapting traditional instructional practices. In addition, perceptions from colleagues and parents often presented as challenges, and the participants in this study sought ways to overcome these barriers.

4.2. Nature and Scope of i-STEM Education

Three key themes emerged from analyzing how the participants conceptualized the nature and scope of i-STEM within their schools and classrooms: authentic contexts and problems, connecting i-STEM into the formal curriculum, and disciplinary emphasis.

4.2.1. Authentic Contexts and Problems

Seven of the eleven participants (64%) argued that a foundational aspect of i-STEM is situating it within an authentic, real-world context that students can relate to. For example, Gary drew on global challenges such as the "acidification of the oceans" or "green energy" to help his secondary school students make connections between STEM concepts and their everyday lives, "to truly understand why that is important, because it affects you". However, Gary also noted that connecting concepts and contexts in authentic ways also extends the time required for teaching, explaining,

> We are going to spend two weeks on . . . chemical reactions but we should spend another two to three weeks on ocean acidification to truly understand what is changing about the environment and what climate change means because they go out of here understanding now, I hope, some of them, that it's important.

The notion of authenticity and real-world links in i-STEM was also important to Sam, to address his concerns about student disengagement in their science learning. Prior to introducing i-STEM at his school, Sam found "they [students] had no sense of meaning in what they were doing in my classes, and to tell you the truth, that was really disheartening". He felt that he could not "keep ignoring this" and that he did not enjoy coming to work when "students do not see the value in what I am doing or have not made any connections outside of this classroom". Sam developed his i-STEM curriculum with a focus on interdisciplinary connections, so that instead of seeing the disciplines as separate "silos", he reconsidered them as "pillars" from which to build a new curriculum:

> What if we think of these silos as pillars, as a support structure? What if they are kind of foundation stones? What if on top of that we build an integration model where we build the beams or the spokes that connect all the individual silo learning areas or supports? . . .the spokes lead to the disciplines.

4.2.2. Connecting i-STEM into the Curriculum

Six of the eleven participants (55%) discussed the role of connecting i-STEM with the mandated curriculum, and as reported above, teachers identified tensions with introducing an integrated approach (i.e., i-STEM) into the lower and middle school years, when students would then shift to a disciplinary siloed approach and high-stakes testing in their final two years of schooling. For these reasons, Gary explained that he gets "no traction in the senior school on STEM at all, the teachers are not interested". While he tried to support these teachers by offering them "a few examples of how they could do it [integrate disciplines]", Gary felt as though he is "never going to sell [integrated] STEM into middle school and senior school, they just will not give me the airtime".

In the face of the pressures of formal curriculum requirements and the absence of an explicit, government-endorsed i-STEM curriculum, along with resistance from parents and colleagues, teachers had to make do and work around existing structures. Cate explained that she must "justify it [i-STEM] back to the [mandated] curriculum", noting that "we have got a number of teachers that try and integrate STEM activities as they see that might complement existing courses". Cate explained that in her senior biology class, she tries to connect learning across disciplines; however, she acknowledged that she has not yet "found a way to condense the curriculum". Kay explained that she sees "huge potential for [integrated] STEM in physics and PE [physical education]", although she has not yet been able to realize that potential.

In terms of planning for i-STEM, teachers utilized different approaches. Kay drew from the Victorian curriculum across the different STEM subjects (science, mathematics, technology) and cross-curriculum capabilities to inform her i-STEM planning, while Denise took ideas from the Victorian science curriculum but also used ideas that came "... in my head" about what might be interesting and relevant to her students. Nicole focused on her students and "what they need and what they're telling us they need". She was less worried about "having it all planned out" and took a more dynamic approach, with planning taking place "in the moment... with the students". This notion of being flexibly responsive to student interest and need was mentioned by many of the participants, as well as the flexibility offered by i-STEM compared with traditional disciplinary approaches. For example, Rohan argued that "the models in science are very rigid. ... With [integrated] STEM, you can manipulate things". Fiona echoed these comments, stating that the "science curriculum is highly structured... you're teaching set concepts, predetermined concepts, everything is strictly defined". In contrast, she explained that she finds that in i-STEM "there's more flexibility, and because of that, you have more input".

4.2.3. Disciplinary Emphasis

Perhaps an unsurprising finding given their subject backgrounds, 10 of the 11 participants (91%) valued and prioritized different subject areas in their thinking, planning, and teaching for i-STEM. For instance, as science teachers, Denise, Cate, Tania, Jane, and Kay primarily taught i-STEM through a science lens, often using their science class as a proxy for i-STEM. Both Rohan and Gary prioritized engineering practices in their approach to i-STEM. Gary felt as though his engineering background provided a unique perspective that helped students' understanding of engineering: "because I am an engineer, we can do certain things that many other teachers cannot and do not understand. I think we can make technology and the understanding of engineering accessible".

Other teachers with arts backgrounds preferred to talk about STEAM (Sam and Nicole), while Kay (science) felt as though the nature of the work students were doing could shift between STEM and STEAM. Fiona (mathematics and science) acknowledged that STEAM was appropriate "if you want to include art" but did not elaborate further. Denise, a science and psychology teacher, emphasized the inclusive aspect of STEAM:

> STEAM, I prefer that to STEM. I just think it opens up more avenues to better inclusivity for students. I hate it when people say, 'Oh, are you a science student or a humanities student?' I am just like, 'Please!' It's the most ridiculous thing I have ever heard.

In summary, while these teachers took different starting points for their i-STEM teaching, they aligned in terms of their perceived view of i-STEM as bringing real-world, authentic issues to the classroom. They valued the curricular freedom and flexibility of i-STEM, where they could infuse their own ideas and experiences and respond to student interest and needs, compared with the perceived constraints of a traditional, siloed STEM curriculum.

4.3. Implementation of i-STEM Education

Three key themes emerged from an analysis of the participants' experiences of implementing i-STEM in their learning contexts: approaches to implementation, assessment in i-STEM, and funding and resources.

4.3.1. Approaches to Implementation

Responses from the participants about their approach to implementing i-STEM revealed a range, from students simply having a "hands-on" experience of physically or digitally making something (n = 6, 55%), to more organized approaches such as problem-based learning (n = 5, 45%). In terms of a problem-based approach, Kay explained that she begins by introducing a problem that students "will often encounter themselves" and then follows with a design thinking approach to solving the problem. Similarly, Cate and Fiona reported implementing i-STEM via problems they had developed for students, whereas Gary invited students to formulate their own problems based on their own interests. Donna utilized both approaches, giving students pre-prepared problems and asking them to develop their own. She emphasized linking problems to community issues such as "trying to help homeless people, or in terms of climate change and natural disasters" in ways that showed "how they [students] can make an impact or make a change".

Seven of the eleven participants (64%) talked about the use of design thinking in their approach to implementing i-STEM. However, while there were some basic similarities in terms of the processes they applied, each teacher brought their own variations. For instance, Kay combined design thinking with problem-based learning, in which students work through a process to "get to a solution that actually solves the problem that they have encountered". Jane noted that her school was developing its own design thinking approach to bring some consistency to their i-STEM teaching, where students completed small projects that explicitly focused on different parts of the design process. At a more general level, Donna saw design thinking as providing an authentic purpose for students' problem solving "just to give them [students] the real, why are we doing this?". Gary was the only participant to name a particular model—Stanford design thinking—that exclusively framed his approach: "where you have got empathize, design, ideate, prototype, test, and I use that exclusively in every STEM-focused activity that I do".

Eight of the eleven participants (73%) talked about the importance of group work in i-STEM connected with the need for students to develop collaborative skills. Different views about group size were expressed, with Rohan noting that group size depended on the task, whereas other teachers were more adamant that students should work in pairs to ensure that work was more equitably distributed. Kay noticed in i-STEM that students "naturally progressed into a group" as they recognized the value of others' ideas and wanted to work together, which she encouraged. Conversely, Cate identified difficulties with group work because of students "arguing [about] whether or not their particular idea should go forward or their iteration of it sort of should be adopted by the group". Difficulties associated with group work were echoed by other teachers, and Nicole identified the need to develop trust within the group, especially so students see value in what they are doing and do not just "muck around".

4.3.2. Assessment in i-STEM

In terms of their i-STEM assessment practices, 5 of the 11 participants (45%) talked about using student presentations or portfolios so students could demonstrate their learning, skills, and interests in various ways. For example, Fiona asked students to include "progress reports" as part of their portfolio submissions, explaining "they talk about some of the struggles that they encountered, how they solved those struggles, and explain how collaboration was part of that process or problem solving was part of that process".

Cate was concerned about how to build authenticity into her assessment practices, so she required her students to "stand up and put forward their proposal", which she linked to an example of working with representatives from the local zoo. She explained, "I would like a stakeholder or someone to be present in the room, someone more formal than just the teacher taking a grade, so it just gives the students the feeling of that real life experience."

Cate also acknowledged that formal assessment has not been a strong focus in her i-STEM classes to date, and that she was considering how to assess the "incredibly difficult" aspect of students' i-STEM skills. Similarly, Rohan noted that students' i-STEM "skills [are] very difficult to assess". Rohan used an assessment rubric that incorporated grades for creativity, teamwork, and research, as well as data use and manipulation. Four other participants also talked about using rubrics in assessing i-STEM, and Denise provided students with these in advance "because it gives them [students] clarity".

Both Sam and Kay outlined that their assessment focused primarily on one STEM discipline. For Sam, while he "only assesses the particular discipline that I am [focusing on]", he was beginning to think about a "cross-curriculum stage". He identified the need for new ways of assessing student learning that consider different areas of the curriculum: ". . .how we can really reflect what is happening inside a STEAM subject and how that learning is valued across the different learning areas or disciplines". While Kay acknowledged that she tries to consider elements of creativity in her assessment, ultimately, she is only "assessing against the science curriculum" because she does "not know how to assess STEM".

Finally, while Nicole wished to develop more diverse forms of student assessment, she experienced tensions between the school's requirements for assessment, which were aligned with senior levels of formal assessment, and her own. Nevertheless, she "adapted" and "changed" current school assessments to make them more suitable to assessing i-STEM, explaining "it can be done, but I think it causes a lot of stress for people if they think that they're not meeting the right assessment tasks [set by the school]".

4.3.3. Funding and Resources

Six of the eleven participants (55%) highlighted that their implementation of i-STEM was hindered by insufficient funding or resources. For instance, Kay, Rohan, Fiona, and Sam all talked about cost as a barrier to obtaining various resources that they felt would enhance their i-STEM teaching. Kay identified i-STEM as "resource heavy", which came with a significant "financial cost"; Fiona talked about resources that she had bought to support i-STEM learning in her school but explained that she was unable to purchase the hydroponic equipment that some students wanted, because "money is [a] big [issue]"; and Rohan identified "that one of the biggest challenges is when you take a AU$30,000 invoice to the principal, and you see the look on his face", which he expressed while laughing.

In summary, there was a great deal of inconsistency amongst teachers' reported approaches to implementing i-STEM, along with uncertainty and stress related to assessment and resourcing issues. In particular, and similar to the goals and outcomes above in Section 4.1, teachers experienced tensions between meeting the requirements of the mandated curriculum and responding to the opportunities they saw in i-STEM.

5. Discussion

The findings from this study are discussed through the lens of the two guiding research questions: how teachers in secondary schools without any formal preparation in STEM integration think about implementing i-STEM within their schools and classrooms; and the issues and challenges that these teachers encounter in both designing and implementing teaching programs that integrate the STEM disciplines in their school contexts. Given increasing interest in implementing i-STEM from teachers and schools and the lack of a formal curriculum or PD opportunities to guide implementation (Deehan et al., 2024), this study is needed to enable the development of more effective supports for teacher learning, which will ultimately yield benefits in terms of students' STEM education.

5.1. How Teachers Think About Integrated STEM

In general, our findings align with the conclusions drawn by Falloon et al. (2020) that i-STEM education tends to be interpreted in a variety of different ways according to the priorities and preferences of different stakeholder groups. Similar to those reported by Xu et al. (2023), the participants' approaches tend to vary based on their academic backgrounds, areas of personal interest, and school opportunities. For example, those with science backgrounds tend to frame i-STEM through a science lens (Denise, Cate, Tania, Jane, and Kay), and those with engineering backgrounds frame their view and approach to i-STEM through engineering practices (Gary and Rohan), while those teachers from a non-STEM background (Sam and Nicole) tended to incorporate a broader view, favoring a STEAM approach (which Denise also favored).

At the same time, some similar characteristic elements emerged within the participants' accounts of curriculum planning and implementation. For example, the use of student-centered learning approaches that emphasized teamwork and collaboration, situating learning within authentic and engaging contexts, and the need to focus on skill development.

The participants commonly expressed a view of i-STEM as more engaging for students than traditional stand-alone subjects (i.e., science) because of opportunities to be flexibly responsive to the students' interests, while allowing them to make links with their own lives and to develop different student skills that can be utilized within other contexts (El-Deghaidy et al., 2017; Lesseig et al., 2016; Maeng et al., 2017; Xu et al., 2023). For these teachers, it appears that i-STEM is seen as both a curriculum and a pedagogy (Margot & Kettler, 2019), and compared with the ideas presented earlier from Murphy et al. (2019) it becomes clear that teachers see value in i-STEM through an educational agenda rather than a political or economic one.

Planning for i-STEM varied amongst the participants, from planning in ways that respond to student ideas (and needs) to working with school-based colleagues and even partnerships with local organizations (i.e., a zoo). Amongst these approaches, individual planning was most common, with group planning only indicated as an approach by three participants (Nicole, Tania, and Jane). Planning in this individual way presents a problem within an i-STEM education context, as the integrated and transdisciplinary nature of i-STEM calls for teachers "to know not just their subject matter, but the content of the other disciplines" (Margot & Kettler, 2019, p. 2). Favoring individual approaches, however, may be related to having suitable and willing teachers within a school, as well as time and support from leadership. We note that several participants identified an almost hostile view towards i-STEM from some of their colleagues, which restricted opportunities for collaborative learning and curriculum development. Nevertheless, the teachers in this study figured out ways to implement i-STEM, driven by an inherent commitment to providing more contemporary, authentic, and/or engaging experiences for their students, despite the challenges they faced within their contexts, which are discussed next.

5.2. Issues and Challenges When Designing and Implementing Integrated STEM

The three broad levels of challenge (i.e., teacher, school, and policy) for teaching i-STEM identified by Corrigan (2020) were all apparent in our data. For instance, at the teacher level, it was clear that the participants were largely unsure about effective means of assessing students' capabilities in i-STEM, such as assessing their ability to be creative or solve problems. Similarly, a lack of content knowledge and confidence about some aspects of STEM, for example, engineering, which has been identified by others (El-Deghaidy et al., 2017; Lesseig et al., 2016; Srikoom et al., 2017), presented at a teacher level. To support teachers, participants identified the need for PD for teaching i-STEM to support content and pedagogical content knowledge, as well as confidence building. Teachers will not only need to develop their content knowledge in one specialist area, but they must also learn how this knowledge relates to and draws on knowledge and skills from other STEM domains. This may be effectively achieved by teachers working together in collaborative interdisciplinary groups to build and share their collective knowledge about the teaching of particular topics in the STEM program of their school. For the teachers within this study, however, challenges at this teacher level may have been less pronounced than those experienced by STEM teachers in general due to their enthusiasm and commitment to teaching STEM in an integrated way, even though they did not have formal PD for teaching i-STEM.

School-level challenges appeared to be the most significant for the teachers in this study, such as an inflexible localized school curriculum that does not foster or embrace transdisciplinary and integrated approaches to teaching and learning. Other challenges at a school level include a lack of buy-in, along with pushback from colleagues about the perceived value of i-STEM, leading to a lack of support for planning and implementing i-STEM in ways that the participating teachers may have enjoyed. Our findings align with Xu et al. (2023), who contend that a shared school-wide vision of STEM education needs to be created to “help teachers understand the need for change and develop sustainable plans for moving STEM teaching and learning forward” (p. 685). Lastly, funding and resources, including funding for teacher PD, were identified as school-level challenges.

Challenges at a policy level appeared to act as both enablers and constraints for these teachers. For example, the absence of an explicit, government-endorsed i-STEM curriculum meant that they found it difficult to convince their colleagues of the value of i-STEM or for i-STEM to have a recognized place in the formal school curriculum. Further, some teachers struggled to know how to assess i-STEM, as noted above, and either created their own rubrics to assess some aspects of i-STEM they deemed important or defaulted to assessing as they would in single disciplinary subjects. However, this lack of an explicit curriculum and the associated formal assessment objectives also meant that teachers were free to develop a curriculum aligned with the needs of their students and contexts and to introduce different kinds of activities and skills into their classrooms. The participants regularly commented on this aspect as important to their own interest and engagement in teaching i-STEM compared with traditional disciplinary subjects, as well as contributing to the interest and engagement of their students.

In addition, the top-down pressures of high-stakes externally assessed senior subjects are a significant factor limiting the growth of i-STEM in Australian schools. While these pressures originate from a policy level, they tend to be amplified at a school level, so that teachers find it challenging to implement any type of integrated curriculum or approach, particularly within the final two years of secondary school. Indeed, many of these teachers reported the detrimental effects of these assessment pressures when seeking to implement i-STEM experiences in junior secondary school contexts. Compounding this policy and the school-level challenge further are the views and the buy-in of colleagues and parents, who are primarily interested in students’ preparedness for, and success in, high-stakes assessments.

6. Conclusions, Limitations, and Implications

Finally, this study demonstrated that without formal PD, and in the absence of a formal or prescribed curriculum, teachers with enthusiasm and commitment towards teaching STEM in integrated ways were able to create their own i-STEM curriculum. However, despite these well-intentioned efforts and reported student gains (e.g., student interest and engagement), the variation in approaches reported by these teachers and the challenges they faced indicate the need for a comprehensive and structured support system. Most evidently, the teachers lacked the knowledge and resources for relevant assessment approaches, and they experienced pressures from within their schools in terms of colleagues’ (unfavorable) perceptions, inflexible curriculum structures, and the absence of a unified school vision for i-STEM, along with a state-based disciplinary testing regime that maintains disciplinary separation.

To support teachers and schools, a sufficiently flexible framework for teaching i-STEM is needed that can be adapted within local contexts to guide learning. We note the recent publication from Johnson et al. (2021), titled "*STEM Road Map 2.0*", as an example of an innovative curriculum design for STEM learning across the continuum of K-12 schooling that could be adapted for use in Australian settings. "*STEM Road Map 2.0*" aims to promote conceptual understanding within an integrated approach that is aligned with the U.S. national curriculum (i.e., Next-Generation Science Standards) and located in contexts and problems relevant to diverse students' lives and contexts. At the same time, it is important to recognize that teachers will require support to develop their i-STEM thinking and practice around salient points, such as ways to assess in i-STEM contexts, without reducing the aspects that teachers and students value. We also note that the participants hardly mentioned mathematics in their examples and experiences of i-STEM, so building teacher confidence and capability to meaningfully integrate mathematics will require support. Given the paucity of formal i-STEM PD programs, such challenges may be addressed through the formation of local communities of practice, whereby teachers can share and develop their knowledge in interdisciplinary networking groups (Leung, 2020).

For i-STEM to become embedded within Australian schools in the way espoused by the Education Council (Australian Education Council, 2015), there are some critical policy issues to address—for example, the top-down pressure of high-stakes assessment in senior science and mathematics subjects. While some policy directives promote i-STEM education, others severely hinder it, as seen in this study when there is a clash between ways teachers want to implement (and assess) i-STEM and the pressures from the school, which have been derived from policy. The teachers in this study were largely aware of such challenges and were motivated to overcome some of them due to their own internal drive in favor of i-STEM education. For other teachers without this same level of motivation, implementing i-STEM may be a "bridge too far". Addressing issues at the policy level requires a multi-faceted approach, beginning with an initial teacher education so that pre-service teachers are exposed to and can practice pedagogical strategies to support interdisciplinary learning, combined with policy initiatives to integrate i-STEM into formal curriculum documents, including how a trajectory of learning might be developed to reduce tensions between junior and senior years.

While the findings and conclusions from this study have important implications for i-STEM education, both in Australia and in other contexts, we note two important limitations. First is the relatively small sample size of 11 teachers from nine schools. Even though an open call was made through sector representatives, only these teachers were willing to take part, which could reflect the number of teachers and schools committed to an integrated way of teaching STEM. Further, due to the small sample size and margin of error, the percentages are not necessarily reflective of the larger population. It could also be that teachers were reluctant to take part due to their high workloads. Second, while interviewing teachers has offered an important perspective, other stakeholder perspectives could be explored too, such as school leaders, parents, and students. Thus, we would recommend that future research in this i-STEM education context explores the perspectives of other stakeholders, along with collecting data through different processes, to continually develop our empirical understanding of i-STEM education in schools.

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Appendix A. Guiding Interview Questions

1. Could you please give me an overview of the integrated STEM curriculum in your school?
2. What influences/influenced you when planning the integrated STEM curriculum?
3. What do you think about when planning to teach an integrated STEM lesson or module?
4. How easy is it to integrate engineering, technology and mathematics into your STEM lessons?
5. What kind of teaching approaches or learning experiences do you think support student learning in integrated STEM?
6. Could you give me a picture of what I might see if I was to walk into a typical integrated STEM lesson—what would the students and teacher/s be doing? How might this be different from regular science or mathematics lessons?
7. What kinds of learning are you looking for in your students in an integrated STEM lesson? How can you tell if that is being achieved?
8. What do you consider are some of the challenges in implementing integrated STEM education?

Appendix B. Summary of Findings: Frequency of Themes

Categories	Themes		Frequency	%
Goals and Outcomes of i-STEM Education	21st Century Skills and Competencies		10	91
	Interest and Engagement		7	64
	Preparation for Future STEM Course Taking		4	36
	Goals and Outcomes for i-STEM Educators		6	55
	Parent and Colleague Perceptions		5	45
Nature and Scope of i-STEM Education	Authentic Contexts and Problems		7	64
	Connecting i-STEM into the Curriculum		6	55
	Disciplinary Emphasis	Science	5	45
		Engineering	2	18
		Arts	3	27
Implementation of i-STEM Education	Approaches to Implementation	Making something	6	55
		Problem-based learning	5	45
		Design thinking frameworks	7	64
		Group work	8	73
	Assessment in i-STEM	Student presentations or portfolios	5	45
		Using rubrics	5	45
		Focus on one discipline	2	18
	Funding and Resources		6	55

References

Australian Curriculum Assessment and Reporting Authority. (2016). *ACARA STEM connections project report*. ACARA. Available online: https://www.australiancurriculum.edu.au/media/3220/stem-connections-report.pdf (accessed on 12 December 2024).

Australian Education Council. (2015). *National STEM school education strategy: A comprehensive plan for science, technology, engineering and mathematics in Australia*; Education Council. Available online: https://www.education.gov.au/download/12532/national-stem-school-education-strategy/23618/national-stem-school-education-strategy/pdf (accessed on 12 December 2024).

Australian Industry Group. (2015). *Progressing STEM skills in Australia*. Available online: https://cdn.aigroup.com.au/Reports/2015/14571_STEM_Skills_Report_Final_-.pdf (accessed on 12 December 2024).

Blackley, S., & Howell, J. (2015). A STEM narrative: 15 years in the making. *Australian Journal of Teacher Education*, *40*(7), 8. [CrossRef]

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77–101. [CrossRef]

Charette, R. N. (2015). STEM sense and nonsense. *Educational Leadership*, *72*(4), 79–83.

Corrigan, D. (2020). *Implementing an integrated STEM education in schools: Five key questions answered*. Monash Education Futures. Available online: https://apo.org.au/node/307630 (accessed on 12 December 2024).

Deehan, J., Danaia, L., Redshaw, S., Dealtry, L., Gersbach, K., & Bi, R. (2024). STEM in the classroom: A scoping review of emerging research on the integration of STEM education within Australian schools. *The Australian Educational Researcher*, *51*, 2231–2254. [CrossRef]

Department of Education and Training. (2022). *STEM education in Victoria*. Available online: https://www.vic.gov.au/about-stem-education-victoria (accessed on 12 December 2024).

El-Deghaidy, H., Mansour, N., Alzaghibi, M., & Alhammad, K. (2017). Context of STEM integration in schools: Views from in-service science teachers. *Eurasia Journal of Mathematics, Science and Technology Education*, *13*(6), 2459–2484. [CrossRef]

Ellis, D., & William, P. J. (2020). STEM Policy in Australia. In C. C. Johnson, M. J. Mohr-Schroeder, T. J. Moore, & L. D. English (Eds.), *Handbook of research on STEM education* (pp. 428–442). Routledge.

Falloon, G., Hatzigianni, M., Bower, M., Forbes, A., & Stevenson, M. (2020). Understanding K-12 STEM education: A framework for developing STEM literacy. *Journal of Science Education and Technology*, *29*, 369–385. [CrossRef]

Freeman, B., Marginson, S., & Tytler, R. (2019). An international view of STEM education. In A. Sahin, & M. Mohr-Schroeder (Eds.), *STEM education 2.0: Myths and truths—What has K-12 STEM education research taught us?* (pp. 350–363) Brill.

Goodrum, D., Druhan, A., & Abbs, J. (2012). *The status and quality of year 11 and 12 science in Australian schools*. Australian Academy of Science. Available online: https://www.science.org.au/files/userfiles/support/reports-and-plans/2015/year11and12report.pdf (accessed on 12 December 2024).

Honey, M., Pearson, G., & Schweingruber, H. (2014). *STEM integration in K-12 Education: Status, prospects, and an agenda for research*. National Research Council. [CrossRef]

Hynes, M. M., Mathis, C., Purzer, S., Rynearson, A., & Siverling, E. (2017). Systematic review of research in P-12 engineering education from 2000–2015. *International Journal of Engineering Education*, *33*(1), 453–462.

Johnson, C. C., Peters-Burton, E. E., & Moore, T. J. (Eds.). (2021). *STEM road map 2.0: A framework for integrated STEM education in the innovation age*. Routledge. [CrossRef]

Kennedy, J. P., Lyons, T., & Quinn, F. (2014). The continuing decline of science and mathematics enrolments in Australian high schools. *Teaching Science*, *60*(2), 34–46.

Larkin, K., & Lowrie, T. (2023). Teaching approaches for STEM integration in pre-and primary school: A systematic qualitative literature review. *International Journal of Science and Mathematics Education*, *21*(Suppl. S1), 11–39. [CrossRef]

Lesseig, K., Nelson, T. H., Slavit, D., & Seidel, R. A. (2016). Supporting middle school teachers' implementation of STEM design challenges. *School Science and Mathematics*, *116*(4), 177–188. [CrossRef]

Leung, A. (2020). Boundary crossing pedagogy in STEM education. *International Journal of STEM Education*, *7*, 15. [CrossRef]

Lowrie, T., Downes, N., & Leonard, S. (2017). *STEM education for all young Australians: A bright spots STEM learning hub foundation paper*. University of Canberra STEM Education Research Centre. Available online: https://www.socialventures.org.au/wp-content/uploads/2024/08/STEM-education-for-all-young-Australians.pdf (accessed on 12 December 2024).

Lyons, T. (2006). Different countries, same science classes: Students' experiences of school science in their own words. *International Journal of Science Education*, *28*(6), 591–613. [CrossRef]

Lyons, T. (2018). Helping students make sense of STEM. *Teaching Science*, *64*(3), 37–43.

Maeng, J. L., Whitworth, B. A., Gonczi, A. L., Navy, S. L., & Wheeler, L. B. (2017). Elementary science teachers' integration of engineering design into science instruction: Results from a randomised controlled trial. *International Journal of Science Education*, *39*(11), 1529–1548. [CrossRef]

Marginson, S., Tytler, R., Freeman, B., & Roberts, K. (2013). *STEM: Country comparisons, international comparisons of science, technology, engineering and mathematics (STEM) education*. Australian Council of Learned Academics. Available online: https://acola.org/wp-content/uploads/2018/12/saf02-stem-country-comparisons.pdf (accessed on 12 December 2024).

Margot, K. C., & Kettler, T. (2019). Teachers' perception of STEM integration and education: A systematic literature review. *International Journal of STEM Education*, *6*(1), 1–16. [CrossRef]

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

Moore, T. J., Johnston, A. C., & Glancy, A. W. (2020). STEM integration: A synthesis of conceptual frameworks and definitions. In C. C. Johnson, M. J. Mohr-Schroeder, T. J. Moore, & L. D. English (Eds.), *Handbook of research on STEM education* (pp. 3–16). Routledge. [CrossRef]

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

Murphy, S., MacDonald, A., Danaia, L., & Wang, C. (2019). An analysis of Australian STEM education strategies. *Policy Futures in Education*, *17*(2), 122–139. [CrossRef]

Nadelson, L. S., & Seifert, A. L. (2013). Perceptions, engagement, and practices of teachers seeking professional development in place-based integrated STEM. *Teacher Education and Practice*, *26*(2), 242–266.

Nadelson, L. S., & Seifert, A. L. (2017). Integrated STEM defined: Contexts, challenges, and the future. *The Journal of Educational Research*, *110*(3), 221–223. [CrossRef]

Office of the Chief Scientist. (2013). *Science, technology, engineering and mathematics in the national interest: A strategic approach*; Australian Government. Available online: https://www.chiefscientist.gov.au/sites/default/files/STEMstrategy290713FINALweb.pdf (accessed on 12 December 2024).

Office of the Chief Scientist. (2014). *Science, technology, engineering, and mathematics: Australia's future*; Australian Government. Available online: https://www.chiefscientist.gov.au/sites/default/files/STEM_AustraliasFuture_Sept2014_Web.pdf (accessed on 12 December 2024).

Office of the Chief Scientist. (2020). *Australia's STEM workforce: Science, technology, engineering, and mathematics*; Australian Government. Available online: https://www.chiefscientist.gov.au/sites/default/files/2020-07/australias_stem_workforce_-_final.pdf (accessed on 12 December 2024).

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. 91–109). Springer. [CrossRef]

Sanders, M. E. (2008). STEM, STEM education, STEMmania. *The Technology Teacher*, *68*(4), 20–26.

Shah, C., Richardson, P., & Watt, H. (2020). *Teaching 'out of field' in STEM subjects in Australia: Evidence from PISA 2015*. Available online: https://www.econstor.eu/bitstream/10419/215639/1/GLO-DP-0511.pdf (accessed on 12 December 2024).

Srikoom, W., Hanuscin, D. L., & Faikhamta, C. (2017). Perceptions of in-service teachers toward teaching STEM in Thailand. *Asia-Pacific Forum on Science Learning and Teaching*, *18*(2), 6.

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.

Tytler, R., Osborne, J., Williams, G., Tytler, K., & Cripps Clark, J. (2008). *Opening up pathways: Engagement in STEM across the primary-secondary school transition*. Australian Department of Education, Employment and Workplace. Available online: https://mset-ed-deakin.org.au/wp-content/uploads/2014/02/STEM_Opening-up-Pathways-July_08.pdf (accessed on 12 December 2024).

Tytler, R., Symington, D., Williams, G., & White, P. (2018). Enlivening STEM education through school-community partnerships. In R. Jorgensen, & K. Larkin (Eds.), *STEM education in the junior secondary: The state of play* (pp. 249–272). Springer.

Victorian Curriculum and Assessment Authority [VCAA]. (n.d.). *Victorian curriculum: Foundation-10*. Available online: https://victoriancurriculum.vcaa.vic.edu.au/ (accessed on 12 December 2024).

Wang, H., Moore, T. J., Roehrig, G. H., & Park, M. S. (2011). STEM integration: Teacher perceptions and practice. *Journal of Pre-College Engineering Education Research (J-PEER)*, *1*(2), 2. [CrossRef]

Xu, L., Fang, S.-C., & Hobbs, L. (2023). 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. [CrossRef]