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STEM 1, 2, 3: Levelling Up in Primary Schools

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Abstract: Recent research advocating the educational value of engaging primary students in authentic integrated STEM inquiry projects also identifies challenges for teachers aspiring to high-quality student-learning experiences. Teachers require support to integrate disciplines, prioritise processes and reasoning over curriculum content, and increase student autonomy in purposeful STEM projects. Within the context of a year-long professional learning program in Australia, an innovative tri-level approach to skill-building for teachers and their students has been developed. The three levels of 'STEM Skills', 'Design Process' and 'Integrated STEM Projects' are intended to successively escalate demands on time, resources and pedagogical change while promoting the development of the dispositions and skills needed to engage in sustained inquiry projects. The teacher participants (n = 11) came from five schools who had just concluded the STEM Academy professional learning program. Semi-structured interviews guided teacher reflection. Data analysis combined inductive and deductive processes to thematize meaning and revealed ways in which the tri-level approach to STEM education supported the development of STEM integration practices. The findings suggest the efficacy of the tri-level approach and its potential value beyond the context in which it was developed.

Keywords: STEM education; professional development; teacher perceptions; interview

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1. Introduction

In Australia, as in other developed countries, declining participation in STEM disciplines has been identified as a significant societal issue because building capacity in the STEM fields is pivotal to maintaining and increasing productivity and international economic competitiveness [1–3]. The national economic agenda in Australia, together with a rationale for a more 'STEM literate' general population [4], led to the National STEM School Strategy 2016–2026 [5]. While this policy calls for increased emphasis on boosting achievement in individual disciplines, particularly mathematics, it also advocates "... a cross-disciplinary approach to teaching that increases student interest in STEM related fields and improves students' problem solving and critical analysis skills" [5] p. 5, beginning in the early years of education. A more comprehensive coverage of policy and research literature pertaining to the Australian context and primary level schooling, can be found in three accessible reports: 'Translating STEM education research into practice' [6], 'STEM education for all young Australians' [7] and, 'Implementing an integrated STEM education in schools' [8]. For this paper, we adopt the generally accepted view that STEM education involves real world problems, integration of the STEM disciplines, promotion of STEM careers and the students' development of general capabilities such as collaboration, communication, creativity, and critical thinking (referred to as 21st Century skills) [9].

A growing body of international research advocates the educational value of engaging primary students (aged approximately 5 to 12 years) in authentic interdisciplinary STEM inquiry projects [3,8] yet also identifies the difficulties that teachers can have in achieving the high-quality student-learning experiences to which they aspire [10,11]. Less research is available to guide the design of effective approaches for supporting teachers through the complexities of moving towards curriculum integration, with a greater focus on thinking and reasoning than on content, and increased student autonomy in STEM projects.

The purpose of this paper is to report an investigation of how teachers have made use of an innovative 'tri-level' approach designed to scaffold the introduction of STEM education in schools and to address some of the challenges that primary teachers face in adopting interdisciplinary STEM education.

1.1. Literature Review

The following review of literature focuses on identifying some of the key challenges primary teachers face when trying to change their practices to engage their students in interdisciplinary STEM education. We have grouped the key issues found in the literature under the broad themes of integration challenges, pedagogical challenges, and student skill development.

1.1.1. Integration Challenges

Challenges related to taking an integrated approach to STEM education can range from a teacher's personal conception of what is meant by STEM education and how the disciplines interact [9], to organizational structures in the school [12] that may inhibit integrative practices. Although discipline-based constraints are less rigid for Primary teachers than Secondary teachers [11], the reality is that there is no official STEM curriculum Teachers remain accountable to assessing student outcomes prescribed by separate syllabus documents [13] and little official guidance for integration is provided [14] in official documents. A traditional view of separate disciplines or 'subject areas' leads teachers to look for commonalities in the content in each discipline as the starting point for integration, but such overlaps are not easily detected. Dissolving the boundaries between disciplines is more likely to be successful when the focus is on the thinking, processes, capabilities and skills needed by students to solve rich contextualized problems, with the problem context driving the knowledge development [15]. Yet, even enthusiastic teachers are often constrained by school structures such as scope and sequence plans for curriculum implementation and subject-based timetabling [10,16]. For example, it is common in Primary schools to have a daily designated Numeracy hour across the school, or for a grade to implement a pre-prepared science unit of work in the same weeks of the school term, making it difficult to introduce new topics or to blend subjects. Moving away from shared resources and routines can also be challenging for teachers who lack depth of knowledge or confidence in one or more of the STEM disciplines [17].

The feelings of insecurity experienced by some teachers can be accentuated by the additional challenge of working in real-life contexts to solve actual problems, which usually requires a more sustained project-based learning approach. Two of the difficulties faced by teachers are finding the time needed within a structured school curriculum and gaining access to resources needed for sustained projects [11,18]. Genuine open-endedness of solutions makes predicting a pathway through a project problematic and traditional forward-planning strategies largely unsuitable. Hence, teachers need to find new ways to document 'on-the-go' teaching activities and manage both time and resources [13].

1.1.2. Pedagogical Challenges

Pedagogical challenges arise when teachers attempt to increase their use of student-led inquiry to open-up opportunities for the 21st Century learning skills of communication, collaboration, creativity, and critical thinking [9]. The shift away from teacher-led instruction towards student led-instruction can be problematic for teachers who need to reconceptualise their role in the learning process and change their usual repertoire of classroom practices [13,16,19]. A source of difficulty for some teachers is their lack of experience with orchestrating the 'engineering' component of STEM, which typically involves steering students through a design-make-test-redesign process [9]. The many uncertainties inherent in student-led investigations and the increased level of student decision-making can be unsettling for both teachers and students [11]. Indeed, some studies have found that teachers did not believe their students capable of working through self-directed STEM problems [16,20].

1.1.3. Student Skill Development

The development of student skills is also necessary for the successful implementation of integrated STEM inquiry. Students accustomed to high levels of teacher direction, or a competitive classroom environment are often reluctant to show their creativity, share their ideas, collaborate with classmates, or make and justify decisions. Studies have revealed the importance of allowing students to fail during the engineering process and to value the opportunity to learn from failure [21,22]. Building the communication and collaboration skills that are needed to work productively in teams is difficult for some students and can create barriers to full participation in STEM education [6,13].

2. Materials and Methods

2.1. Research Design

The exploratory qualitative study reported in this paper sought to address the research question: What are primary teachers' perceptions of the usefulness of the tri-levels approach to STEM education for supporting the development of STEM integration practices in their own classrooms and in their schools?

To address this question, it was necessary to gather data directly from teachers who have experienced the tri-level approach. Semi-structure interview was selected as a suitable method to collect data from the teachers, as it is versatile, flexible and appropriate for use with both individuals and groups [23] and allows teachers to express their perspectives in their own words.

2.2. Study Context and Participants

The context for the study reported in this paper is a university school outreach program, the University of Sydney STEM Teacher Enrichment Academy. Begun in 2017, the Primary STEM program involves a multi-disciplinary team of educators working with groups of teachers from a variety of schools in a year-long professional learning program. The dual aims are to develop the STEM education capabilities of primary teachers and their students as they work towards a substantial interdisciplinary project and to encourage future engagement with STEM careers. It is part of the Primary Program philosophy that teachers are not provided with units of work, but rather supported to create their own projects in response to their students' interests and their local contexts. Previously conducted evaluation research has established the efficacy of the overall program, with significant changes in teachers' pedagogical practices, students' engagement in STEM learning and their career aspirations shown to have occurred [10,24]. Therefore, the efficacy of the program itself is not the subject of this paper, but a core component of program. In 2019, in response to diversity in the 'readiness' of teacher cohorts to embrace interdisciplinary STEM education, an innovative tri-level approach was embedded within the existing program. The aim was to scaffold teachers more deliberately through the integration, pedagogical and student-skill challenges we had observed. Across the levels (see Table 1), there is increasing demand for pedagogical change, application of student skills and autonomy, and for curriculum integration. School groups are encouraged to work at whichever level/s best suits their current needs but aspire to begin Level 3 before the end of the year-long Academy program.

The participants in this study came from a cohort of schools who began the Academy program at the beginning of 2020, experienced a pause the program due to the COVID-19 pandemic, and concluded the program in 2021. The interruption of the program meant that the program bridged two school years and the teachers began working with a new group of students half-way through the program. As a result, some schools found that they were not ready to begin a Level 3 STEM project before the end of the Academy program. All 19 schools in the cohort were invited to join the study, but only five schools participated in the interviews during the limited time available between the end of the program and the commencement of school holidays. The teacher sample (n = 11) represented 16% of teachers in the program, sufficient to provide viable data to address the research question.

Table 1. Overview of the Sydney STEM Academy (Primary) Tri-level approach.

Level Title	Purpose and Characteristics	Examples
Level 1 STEM Skills	Short (e.g., 15 min), focused, repeatable tasks to develop students' basic skills and learning attitudes. Can be embedded within any curriculum area or used as lesson breaks.	Collaborative group work using clearly defined assigned roles Active-listening and careful explanation of ideas Quick construction challenges (learning from failure) Basic robot programming Collecting, displaying and interpreting data Self-reflection on learning Observation and recording techniques, including representational drawing
Level 2 Design Process	Substantial tasks to develop design and/or inquiry processes. Usually embedded within the Science curriculum or other existing unit of work containing a suitable problem/design context. May emphasize specific phases or involve a full plan/design—make—test—redesign process.	Designing a wind-powered car within a unit of work on forces Hypothesis testing and data-based decision-making when changing the wing-length of a paper airplane or helicopter. Proposing creative solutions to a watering problem with plants, following information research.
Level 3 STEM Projects	Sustained multi-disciplinary projects to solve authentic problems or complete student-driven inquiries. Involvement with the broader community and sources of expertise. Focus on general capabilities like critical thinking, collaboration, communication, creativity. Responsiveness to emerging needs for new knowledge or skills as the project evolves.	Restoring an ecosystem like a pond or barren patch of land Developing more sustainable practices in the school like rubbish management and recycling Repurposing an area of the playground or a room to better meet the diverse needs of students Designing a way to honor the history and/or cultural heritage of the school or local area.

Table 2 provides demographic information for the participating schools, drawn from the publicly available data published by the government (https://www.myschool.edu.au (accessed on 18 October 2022). The Index of Community Socio-educational Advantage (ICSEA) is a scale of socio- educational advantage that is computed for each school. The average value for Australia is 1000. The school ICSEA percentile indicates where the school is placed on the Australian scale of ICSEA. All the schools participating in the study were above the Australian average. For example, School D is in the 77th percentile which means that this school is more educationally advantaged than 77% of schools in Australia. We believe the uniformity of educational advantage in this sample to be a coincidence as the STEM Academy includes a wide range of school types. The Language Backgrounds Other Than English (LBOTE) percentage indicates the proportion of students whose home language is not English.

Table 2. School demographics.

School Group (*n*)	Location	Type	Sector	ICSEA	ICSEA Percentile	Teachers	Students	LBOTE
A group (4)	Regional city	Primary	Govt.	1092	83	14	318	17%
B group (2)	Regional city	Prim & Sec	Non-Gov	1097	84	62	618	23%
C group (3)	Capital city	Primary	Govt.	1119	90	49	908	68%
D individual (1)	Capital city	Primary	Govt.	1070	77	10	211	46%
E individual (1) *	Capital city	Prim & Sec	Non-Gov	1068	98	113	1019	19%

* All-girls school. Note: Column 1 indicates the number of teachers participating in the interview and whether it was an individual or group interview.

2.3. Data Collection and Analysis

The interview protocol consisted of five open-ended questions designed to prompt the teachers to express their experiences and views about the tri-level approach. The first question asked, 'To what extent did you make use of the three STEM levels in your own classroom/to support other teachers in the school?', followed by three questions, one focusing on each of the levels. The final question invited further comments about the tri-level approach. Secondary prompt questions were pre-planned and used to elicit further details as needed. For example, 'What are some examples of Level 1 activities that you used? Were there noticeable improvements in your students' skills?'

The STEM team leaders at each school were emailed an invitation to participate in the study, together with a Participant Information Statement describing the study and Participant Consent Forms. Teachers could opt for an individual or school-group interview, conducted online via Zoom. The choice was offered partly to allow the teachers flexibility to fit an interview into their busy end-of-year work schedules, and partly because they had worked as a team throughout the Academy program and might prefer collective responses to the interview questions. During the three group interviews, for each question, the interviewer invited any teacher who had not spoken to add further comments. The interviewer tried to be alert to non-verbal cues of individuals, such as head-nodding or frowning, to judge the need for follow-up probes on a point made by another interviewee. The two individual interviewees were team leaders for their school and shifted between offering personal perspectives and experiences, and their perceptions of the views and experiences of other teachers in their team. In the analysis and the presentation of results, for all participant responses, we have tried to retain indicators of individual perceptions and collective responses—in particular, by retaining "I" and 'we" in quotations. A copy of the interview questions was provided to participants in advance. All interviews were conducted by the same researcher to provide a uniform approach. Interviews took approximately 30 min for individual interviews, and up to 50 min for group interviews. Interviews were audio-recorded and transcribed verbatim for later analysis. To protect anonymity, we removed teacher and school names from the interview transcripts and applied a letter code to delineate schools for analysis.

Thematic analysis techniques were applied to yield a rich and detailed account of the data [25]. To increase the credibility of the analysis outcomes, a two-phase 'hybrid' approach was used in which both inductive and deductive techniques were applied [26]. In phase 1, two researchers worked independently to read the interview transcripts to gain an understanding of the nature of the content before identifying codes and categories within the participant responses to the interview questions. Phase 2 analysis involved the two researchers in a process of iteratively comparing the two sets of categories and consolidating them in various ways [27], progressing toward the development of themes. The comparison process revealed commonalities leading to the identification of major categories that linked to teachers' perceptions of the tri-level approach (see Table 3 for an example of the process outcomes). This second phase of analysis assisted in corroborating and legitimating [26] coded themes that were formed through clustering the categories that were interrelated.

Table 3. Excerpt of second phase analysis and the identification of common categories.

Interview Question Link	Researcher 1 Coding	Researcher 2 Coding	Matched Codes/Major Categories Leading to Themes
Teacher perceptions (overall) of three levels	Align Worthwhile Sequence from L1 Level 1 foundation Professional Learning Positive Merged levels Mathematics Links Ability level	Progression/sequence Welcomed structure Positive Merged levels Student need Flexible sequence Great gains Worthwhile Clearly defined structure Cyclic Manageable Logical	Worthwhile/positive Sequenced progression Merged levels/flexible

3. Results

The results of the study have been organized into three sections that are related to the three clusters of questions in the interview protocol, with the 12 identified themes forming sub-sections.

3.1. Extent to Which They Utilised the Levelled Approach within Their Own Classroom and to Support Teachers

3.1.1. Worthwhile Approach

Teachers across all five schools perceived the use of the tri-levels approach as a worthwhile way to introduce and scaffold STEM practices. Comments by teachers from School C highlighted that the approach was a "logical process and a logical sequence [that] just made perfect sense" and that it was a "very easy way to implement [STEM]" particularly for "anyone that's a little bit worried or hesitant about a STEM approach". The three-level approach was considered a helpful guide by School A where teachers reflected it was "clearly detailed" and "tied in nicely" to Department practices. One teacher at School A welcomed the structure the approach brought to their implementation of STEM noting that "without that structure, I suppose, STEM for myself has felt a bit a bit loose, and that I'm not too sure where to go".

3.1.2. Sequenced Progression

The tri-level approach was seen in a positive light as a sequenced structure to gradually introduce STEM and progressively build on students' prior skills and knowledge developed at each level. Schools followed the suggested three levels approach reflecting on the foundation each level provided for the next, for example:

- " . . . the foundation of the success of the whole program. If you don't get [level] one; two and three can't happen as successfully as it should . . . there was definitely a step up [in levels] in terms of content and previous knowledge" [School C]
- "We definitely started with the level one and two activities all levels in the sequence that they were explained to us, level ones first to build skills and then level two is around design tasks. So we did use them in sequence" [School B]
- "Level one skills really did give a great foundation to move into level two. And again, the level two skills gave a great foundation to moving to a Level three" [School D]

3.1.3. Flexible Approach

Although schools followed the sequence of level 1, level 2, level 3 when introducing the approach, they acknowledged the flexibility in revisiting certain levels during implementation and discussed the reiterative, cyclic nature of the approach based on the needs of students. Revisiting Level 1 skills-type tasks was mentioned by the schools:

- "We needed to revisit level one tasks throughout" [School B]
- " . . . just sort of went back a little bit to level one" [School A]

School C commented on the flexibility in relation to the duration of each level stating "there was not a set time limit that you got to level two . . . we could spend as much time as we needed to, based on our class and based on the skills". School E's implementation "merged the three levels" where the three levels were more of a continuum than strictly separate. Teachers stated they could "dip in and wherever there was a need—if there was a certain skill missing from the group of children, we would plug that gap before moving on to the Level 2". This moving between levels based on student need was similarly noted by School C who reflected that their "year 4 kids needed not as long on the level ones at the start of the year" because they already came with teamwork skills. The flexibility of the tri-level approach also supported the teachers' learning as well as the students' learning at School A:

- "level one stage sort of did go for quite a good while, just to really build up the skills and the language and the resilience and to build that teacher efficacy as well and the confidence" [School C]

3.1.4. Building Teacher Capabilities

When implementing professional learning on the STEM project within their schools, teachers discussed how the tri-level approach helped build teacher capabilities and confidence in teaching STEM:

- "We actually did some little tasks in our stage staff meetings. Many of the staff completed the tasks, which I think was great. So they get a feel for the style. They have an understanding ... those level one tasks, I think we were really trying to build the capacity of the teachers as well. And that was building the confidence in the teacher was really a strong point ... I think we started off slow and that proved to be quite effective because as confidence grew, we could change the tasks" [School A]
- " ... we ran professional learning for the other staff ... so all the classrooms ran level 1 activities to engage which were videoed to engage the community into our project" [School D]
- "I think we use a lot of examples that were used from the day that we spent together ... that was helpful to get our team up and running and I guess give them confidence and that they could, you know, just replicate what we'd already done in that PD day" [School B]

Professional learning based on the tri-level approach also pinpointed specific levels for which teachers may require further support to build their capabilities to implement STEM. For example, one teacher from School B reflected, "I do see our staff needing a lot more, understanding behind ... the how to, and the why, behind designing a Level three project", likewise teachers at School C noticed that the other teachers "struggled to integrate them [the activities] well into other learning areas".

3.2. Specific Comments on Implementing Level 1, Level 2 and Level 3

3.2.1. Clear Purpose of Each Level

In the interviews, teachers responded to questions regarding each of the three levels of the approach. A key theme that emerged across the five schools was the similarity in the way teachers described the purpose of each level. Level 1 was often referred to as skill-building. For example, School B described Level 1 as a foundational step to "first to build skills" then Level 2 involving the thinking processes "around design tasks". Teachers from School B further described Level 2 as "learning the process and being fluent with the design process". Level 3 was described as having to "be more driven by the students ... it has to be a bit more open" (School D), involving an authentic "culminating project" (School B).

3.2.2. Redesign, Reflect, Repeat (The 3Rs)

As previously stated, Level 2 was seen by teachers as an opportunity for students to develop their design thinking processes. Teachers' comments on Level 2 often referenced the iterative aspects of design and re-design, create and re-create, repeat, and reflect. Teachers from School B talked about students "making and breaking and remaking". School C teachers referred to students using processes of "planning and then creating new ways" to solve the tasks. Schools A, B and C all discussed the process of going back, revisiting and reflecting, for example:

- " ... we definitely use that process to make sure that the kids aren't just sticking with their first idea and being done, but actually going back and thinking what worked, what didn't" [School C]
- " ... we got everyone together and let the groups present their way of doing it ... then allowed the other groups to learn from that and to go back and try to use some similar thoughts and ideas in order to get success" [School B]
- " ... we could see that students were improving on their previous successes or remembering that how they failed and how they could improve their designs from that" [School A]

- " ... go back and make something different now and see if we can improve on it' [School C]
- "go back and revisit something ... come back and redo the task and then be able to apply that previous experience and how they can tweak and improve the process" [School A]

3.2.3. Building Student Capabilities

Teachers reported that the group collaboration model implemented within Level 1 assisted in developing students' teamwork skills by identifying particular roles. These roles were perceived as providing a positive structure within which students could build their capacity to cooperate. The structure of the roles allowed students to learn "how to cooperate with one another" (School C) and supported students to be "able to listen to and almost blend different team member's ideas together to form a single idea" (School B). Conversely, teachers also mentioned how some students found group collaboration challenging. School A described how students "struggled to work in the group they've been placed into to start with and to get themselves organised and to sort of agree on a plan of attack".

3.2.4. The Challenge of Curriculum Integration

Comments related to Level 3 suggested that although authentic transdisciplinary projects were the goal, teachers "struggled to integrate" still seeing tasks as "additional learning activities" (School B). One teacher from School B continued, "I think upon my reflection of the project, the pedagogy behind the transdisciplinary model of STEM is not fully understood in an integrated approach to KLAs, we're not there yet". School C's teachers similarly reflected that "there was a little bit of design going on, but it wasn't you know, wasn't that huge overarching integrated unit". This challenge of programming differently was also identified by School B, "we didn't see the process of backward mapping ... seeing cross-curriculum links ... coming up with a loose plan ... being guided by students and their thinking".

3.2.5. Teacher-Led vs. Student-Led

A second aspect of the difficulty teachers expressed with implementing Level 3 of the approach was who was leading the project. Schools generally acknowledged that they wanted the projects to be student-led:

- "we were trying to give opportunities for the students to identify a community problem ... we realized that we were directing a little too much. And then so we said, right, we'll step back, and we'll do it, let them find it" [School B]
- "I think we need to survey students and really try to find out what they really want to change ... they weren't strictly driven by the students and that's why we really thought we never really got to level three in its purest form" [School A]
- "We were involved in the refurbishment of Gable Park ... that wasn't driven by the students we were just approached by the council [School A]

However, at this point in time, most projects were still mainly teacher-led. Teachers from School D said that during level 3 "everyone in the class designed the automatic watering system". They felt this addressed the relevant syllabus content, yet the question remained: "How we can have a topic that is broad enough that will cover the syllabus but that is allowing the students to take the project in their own direction?"

3.3. Any Further or Final Comments on the Tri-Levels Approach

3.3.1. Challenges/Obstacles

When reflecting on utilising the tri-level approach, teachers spoke of a range of challenges they anticipated as they progressed the STEM education development that was underway in their schools. These perceived challenges included:

- Upscaling—"I think a challenge for us moving forward will be school wide how we approach level one, two and three" (School C)

- Staff turnover—"we will need to address moving forward what you do when you've got new teachers coming onto a stage, but the kids are ready to go" (School C)
- Covering content—"a hurdle is definitely staff and executive, in terms of showing them and demonstrating that you are meeting outcomes through this approach" (School C)
- Teacher capacity—"Level 3 is our real challenge because it has to have students and teachers who are passionate" (School D), "I think in the project, they [teachers] felt quite overwhelmed and quite challenged" (School B)
- Time—"having that dedicated time . . . it's hard . . . but when you see that integrating things makes so much more sense to the kids . . . it's not an add-on" (School E), " . . . we are always trying to support staff . . . give them the time to actually stop and look and think, how can I link STEM to my curriculum?" (School A)

3.3.2. Supportive Embedded Practices

Final comments from teachers identified classroom and school-wide practices that would support the sustainability of STEM in their schools. School E discussed a "drip-fed" model of delivery where they brought other teachers on the journey by "dipping into the skills" once a week to build "tiers of understanding [of STEM] and of the processes". The tri-level approach became an "embedded process" across the whole staff at School A. The team of teachers reflected that "working through them" the three levels, was a process "we take onboard, and the other teachers take onboard". One School A teacher stated:

- "Going slow and starting with that level one and embedding that and having that support, especially for the teachers, has meant that STEM is sort of embedded and moving forward, everybody is interested in STEM and everybody's contributing"

These types of embedded practices were also reflected on as having impacted on student learning as well as teacher learning. For example, teachers at School A discussed their school's shift in practice and the impact these changes had noting, " . . . our creative thinking process is . . . we changed our maths, we've changed a lot of things we see such an improvement in children that used to sit back and perhaps were not as engaged before".

3.3.3. Culture and Ownership

Teacher reflections highlighted STEM as a journey, as a culture, and as a school ethos. The sustainability of the tri-level approach at School C in the long term "was going to be something that could become part of the culture of the school," the teachers could see the "benefit of doing those three stages". School STEM culture was also recognised by School E, in relation to student culture; "the kids just wanted to keep testing and testing—go back to the first design, tweak it, work with a partner and see what he/she did to the design . . . It created a culture". At School A, the teachers thought that the tri-level approach was "changing the ethos of the school" where they could "see the progress happening" and see that "everybody's excited by STEM". The team reflected that "we've always got STEM at the back of our minds, and we always think—how can we integrate STEM?". This observation of progress, a shift in culture, was also visible in the response from School C:

- "I think that a lot of teachers, and I was definitely one of them, at the beginning of the journey you think of STEM as needing to have something to show for your work at the end. You have to have made something. And getting past that, I think is a big step because it's not about what you've created. It's about what you've learned along the way"

4. Discussion

In this paper we address the research question: What are primary teachers' perceptions of the usefulness of the tri-levels approach to STEM education for supporting the development of STEM integration practices in their own classrooms and in their schools?

A summative response to the research question is that the teachers from all five schools found the approach to be useful, with each level having a clear purpose that focused their efforts and gave a sense of progress as they moved to the next level. The teachers saw the benefit of working through the levels sequentially, though with some flexibility to meet student needs as they arose. Not only was the approach useful in the teachers' own classrooms, but they saw it as a helpful structure for involving other teachers and supporting school-wide change. Teachers spoke of building 'supportive embedded practices' and 'culture and ownership' of STEM education using the tri-level approach as "tiers of understanding and of the processes". Due to the interruption of the pandemic, most schools had only just begun moving their practice into Level 3 Integrated STEM projects, so were still grappling with some of the associated challenges.

In reflecting on the results from the interview data, we return to the three broad areas of challenge for teachers that were identified in the review of literature, that is, integration challenges, pedagogical challenges and student skill development. Aligning our findings to existing research in this way highlights the potential of the tri-level approach to assist teachers in meeting some of these challenges and reveals the current study's contribution to research in the STEM education field. However, we once again acknowledge that the data does not come from a representative sample of the schools participating in the STEM Academy program, and that the challenges faced by other schools might be different.

4.1. Integration Challenges

The results themes of 'The challenge of curriculum integration' and 'Worthwhile approach' provide some insights into how the teachers were managing some of the organisational and syllabus-related challenges involved in moving towards integrated STEM education.

It seems that working with their classes on Level 1 STEM Skills and Level 2 Design Process helped the teachers realise the importance of valuing thinking and working skills, rather than only focusing of content from separate disciplines, a challenge identified in previous research [9,15]. The nature of Level 1 and 2 STEM activities meant that teachers could nest them into existing organisational structures and teaching programs without much disruption. However, as the teachers began attempting Level 3 project work, they encountered some of the challenges reported by other studies, such as finding enough time for project work and shifting from a reliance on forward-planning to a more responsive 'backward mapping' of student-learning and syllabus coverage [11,13,18].

4.2. Pedagogical Challenges

The themes of 'Teacher-led vs. student-led' and 'Building teacher capabilities' yielded some information about the teachers' perceptions of pedagogical changes. Previous research has pointed to the difficulties teachers often encounter in knowing how to promote development of general capabilities or 21st Century learning skills (communication, collaboration, creativity, and critical thinking) in their students [9]. Another issue previously identified is teachers' lack of experience with the design process [9]. The teachers' experiences with Level 1 and 2 lessons appear to have alleviated these challenges. Without explicitly labelling 21st Century learning skills the teachers frequently referred to them when talking about what their students had learned, as illustrated by comments such as, " ... able to listen to and almost blend different team member's ideas together to form a single idea", and " ... going back and thinking what worked, what didn't". The teachers spoke of their own confidence building alongside their students' skill development, as expressed in a statement explaining the benefits of spending time " ... to really build up the skills and the language and the resilience and to build that teacher efficacy as well and the confidence".

However, some of the teachers talked about the ongoing pedagogical challenges they faced as they attempted to move into Level 3 Integrated projects, particularly regarding further shifts towards more student-led decision-making, which resonates with previous research [13,16,19]. From our point of view, this raises the question of whether the pedagogical gap between Levels 2 and 3 may be too large for some teachers. It is difficult to ascertain if the loss of momentum experienced by the teachers was due to the pandemic interruptions, or whether additional scaffolding provided by an intermediary level would be of general benefit.

4.3. Student Skill Development

The teachers had much to say about the development of their students' skills through engaging with Level 1 and 2 tasks, with information running through at least five of the results themes. Previous research has emphasised the importance of allowing students to fail during the engineering process and to value the opportunity to learn from failure [21,22]. Teachers obviously also saw this as educationally valuable, exemplified in the quotation, " . . . we could see that students were improving on their previous successes or remembering that how they failed and how they could improve their designs from that".

4.4. Limitations of the Study

The data for this study was drawn from a small sample of educationally advantaged schools in city and suburban locations and therefore was not representative of the variety of schools involved in the STEM Academy programs. Additionally, the extent to which the interruption of the pandemic influenced the implementation of the tri-level approach, and therefore the results, is unclear. Expanding the study to include current and future cohorts of schools from a broader range of geographic and socio-economic contexts would provide more robust and complex data.

The current study relied on teacher-reported data from a single interview. Although sufficient for an initial exploratory study, future studies could include research methods such as case studies, to capture the complexities of particular school contexts via a range of data sources. Such studies could go beyond reporting teacher perceptions of usefulness to include explorations of the how the affordances of the tri-level approach interact with teacher and student characteristics in each setting. Our informal observations of all the Academy schools suggest the adaptability and efficacy of the tri-level approach in meeting the needs of diverse schools but we lack methodically collected data.

5. Conclusions

The use of three levels for scaffolding the development of STEM education in primary schools appears to be unique, as to-date we have not found any similar approaches reported in the literature. According to the perceptions expressed by the limited sample of teachers in this study, the tri-level approach of *STEM Skills*, *Design Process* and *Integrated STEM Projects* provided a flexible and effective scaffold to making some of the changes in practice required to move towards integrated STEM projects. Our initial findings suggest that the tri-level approach may have potential to support other schools to embed STEM education, but a more thorough investigation of the application of the tri-level approach in diverse school contexts is warranted before recommendations can be made with confidence.

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