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Bringing engineering into primary science classrooms using engineering design and community of practice approach—An evaluation of STEM × Play program

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Due to the rapid growth of STEM-skilled jobs, there is an urge of introducing engineering in earlier years of schooling to not only flourish students' motivation and interest but to also acquire the required skills for surviving in the high digital demand environment. This paper aims to share an innovative pedagogy–STEM × Play in-curriculum program and to report the post-program evaluation of primary school students' perceptions about and attitudes toward learning STEM and teachers' perception of teaching STEM. There was evidence of positive student learning outcomes including critical skills needed for STEM professions such as comfort with failure, collaboration, critical thinking and problem solving. Mentors from universities and industries were found crucial for improving teachers' STEM skills.

KEYWORDS

STEM, engineering design approach, community of practice, theory of change, STEM × Play

1 Introduction

As reported in Burnett et al. (2019), the existing engineering education system is not coping with the rapid pace of change in digital structures and systems. To meet the future expectations and global workforce demand for economic challenges, urgent action in the reform of engineering education systems is required to develop proficiencies in Science, Technology, Engineering and Mathematics (STEM) education. Education policymakers, STEM educators, engineering and related industries are stressing the urgency for improving students' STEM knowledge and uptake of STEM careers (Marginson et al., 2013). However, results of studies (e.g., McDonald, 2016) have revealed that students' decreasing interests in STEM subjects are "attributed to transmissive, teacher-centered pedagogies; perceived irrelevancy of school science to the real world; heavy, difficult and content-driven curriculum . . ." (p. 536). Among different impacting factors, teaching pedagogy bears the most significant influence on students' motivation and interest in studying mathematics and science in school (Krapp and Prenzel, 2011). Thus, researchers (e.g., English and King, 2015; McDonald, 2016) have called for efforts that promote engineering-based problem solving, inquiry-based pedagogical practices as well as integration of technology and engineering in earlier years of schooling due to the decline of students' interest in science and mathematics at an early age.

However, the low visibility of engineering in K-12 education has adversely impacted students' motivation in studying STEM subjects (Corrigan and Aikens, 2020). Findings of English's (2015) study indicated that early learning experiences in engineering and technology could enhance students' higher order thinking, problem solving skills and academic achievement. Thus, early incorporation of engineering experiences into the classroom can extend students' appreciation and awareness of STEM subjects (English et al., 2013) and better facilitate students to pursue STEM and related subjects in high school. Subsequently, the demand of teaching engineering knowledge as early as from primary schools was emerged.

This paper aims to share an innovative pedagogy that brings engineering into primary science classrooms using engineering design and community of practice approach and to report the evaluation of primary school students' perceptions about and attitudes toward learning STEM and teachers' perception of teaching STEM after engaging into an in-curriculum engineering design process for solving real world problems of local relevance.

2 Literature review

2.1 In-curriculum program pedagogy—Engineering design process

In the past decade, STEM education has been overlooked the potential role of engineering and technology in enabling students to engage in authentic and meaningful scientific activities that are connected to the increasingly digital world (Bybee, 2010). Researchers such as Frykholm and Glasson (2005) identified engineering as a key to locating the entry points for STEM subject integration. Though there is no agreed curriculum for how engineering could be introduced in schools, a common teaching objective under discussion is around teaching broad concepts of the engineering design process through solving real-world challenges (such as Barak, 2013). The engineering design process (also known as the engineering method) is a systematic approach to design and problem-solving that is taught at university-level engineering degree courses and practiced in engineering industry (Atman et al., 2007). Whilst the specific steps of the engineering design process varies slightly amongst engineering education literature (e.g., Dym and Little, 2009), generally, the (iterative) process of engineering design is comprised of the following key stages: (1) Identify and explore the problem, needs and constraints; (2) Explore available solutions to the problem (conceptual design); (3) Evaluate alternative solutions to meet design requirements; (4) Decide on preferred solution; and (5) Detailed design, prototyping, testing and refining the solution.

Pedagogically, a new emphasis of "practice turn" which highlights learning by doing and practising has been put forward in pedagogical shift: a shift from simply teaching the scientific and mathematics content to creating an epistemic culture in where students actively work in authentic scientific inquiry processes (Forman, 2018). Barak (2013) suggested that teaching the engineering design process could serve as an important ingredient in putting STEM into practice. Engaging students in engineering design process is to nurture their engineering thinking and engineering habits of mind (National Research Council [NRI], 2012); they are all about developing students' higher-order capabilities such as systems thinking, problem solving, creativity and collaboration in an interdisciplinary scientific-engineering-technological context (Barak, 2013). More importantly, the unique features of engineering design process–modeling and feasibility analysis–enable students to thoroughly evaluate the viability of each idea when choosing the optimal solution so that their sophisticated thinking can be cultivated (Lin et al., 2021).

Kelley et al. (2020) point out that the engineering design process serves as a platform for situated learning because the problem context is not only authentic but also bounded by science and engineering practices. Engineering creates opportunities to learn as well as apply science knowledge, mathematics knowledge and reasoning during the design process (Lin et al., 2021). Furthermore, when students situate the problem they choose from their local environment and community, they are likely to highly engage in this activity and their learning would be grounded within this context, which makes engineering as well as the other components of STEM appear to be relevant to their life. In this way, the engineering design process can be considered as an entry point for STEM integration.

2.2 Community of practice

Bringing engineering into classroom practice requires strong conceptual knowledge of how to integrate and apply STEM content as well as how students learn (Kelley and Knowles, 2016). Nesmith and Cooper (2021) acknowledged that school children were able to engage in engineering and science investigation when they were facilitated by skilled and knowledgeable teachers. Yet, one of the many but critical factors that obstruct school students being exposed to engineering is that most of the STEM teachers are not trained to integrate STEM into their existing school curriculum (Kelley et al., 2020). Furthermore, many teachers are lacking authentic scientific research and engineering practice because they have never practised as an industry professional or left industry some time ago. Their limited cognitive structure of engineering design thinking hampered their ability to teach STEM (Lin et al., 2021). Therefore, using a community of practice approach alongside the engineering design process to bring in engineering experts to assist teachers' teaching and students' learning may be beneficial.

A community of practice is defined as "groups of people who share a concern, a set of problems, a passion about a topic and who deepen their knowledge and expertise in that area by interacting on an ongoing basis" (Wenger et al., 2002; p. 4). Viewing learning as a production of social structure is the fundamental concept of community of practice. The power of engaging a community of practice in the STEM classroom has been shown to be impactful. For instance, engaging local community experts as STEM partners such as engineering undergraduate students in STEM classrooms can narrow down the power distance; it creates a "safe" environment (free of academic judgment) for school children to develop authentic engineering practice through varieties of activities, problem solving, information seeking and sharing, building things, evaluating and refining outcomes (Kelley and Knowles, 2016). As the idea of a community of practice involves learning on the part of every participant, teachers' active collaboration with STEM partners has the potential to increase teachers' STEM knowledge and foster their understanding about real world engineering practice and scientific inquiry (Kelley et al., 2020).

3 Pedagogical framework

This innovative pedagogy "STEM × Play" program, bringing engineering into primary science classrooms and using engineering design as well as community of practice approach aims to improve primary students' attitudes toward learning STEM and teachers' perception of teaching STEM after engaging into an in-curriculum engineering design process for solving real-world problems. In 2019 the Women in Engineering and IT team at the University (authors' affiliation) introduced this primary school in-curriculum program. Mapped to the Science and Digital Technologies curriculum with indirect links to the Mathematics curriculum (in Australia), the program is a multi-touchpoint targeted at Year 5 and 6 students (aged 10–12).

This program uses engineering design process as pedagogical practice, bringing curriculum content to life and allowing students to work with engineering expertise from the university and industry on real-world problems that interest and are relevant to them. Students undertake engineering design thinking and "future of work" skill development, including computational thinking and collaboration with their peers. The impact on teaching and learning can be sustained post-program, as families are also engaged in the program and teacher professional development embedded to enable long-term capacity development.

3.1 Underlying principle of "STEM × Play"—Theory of change

The STEM × Play program employed a Theory of Change (Weiss, 1995) in its program design. Theory of Change defines long-term goals and then maps backward to identify necessary pre-conditions. It is a specific type of methodology for planning, participation, and evaluation to promote social change when different pre-conditions have been identified potentially responsible for promoting this change. Informed by the evaluation of previous (authors' affiliation) Women in Engineering and IT programs and existing literature as reviewed in the Australian Government's Women in STEM Decadal Plan (Australian Academy of Science, 2018), hands-on learning experiences, building teacher capacity, real world application, multiple meaningful engagements, engaging with families and a community of practice, and early exposure to STEM have been recognized as the necessary pre-conditions for improving primary students' confidence, awareness of opportunities, identity with STEM and interest in STEM play. The diagrammatic Theory of Change for this study is presented in Figure 1.

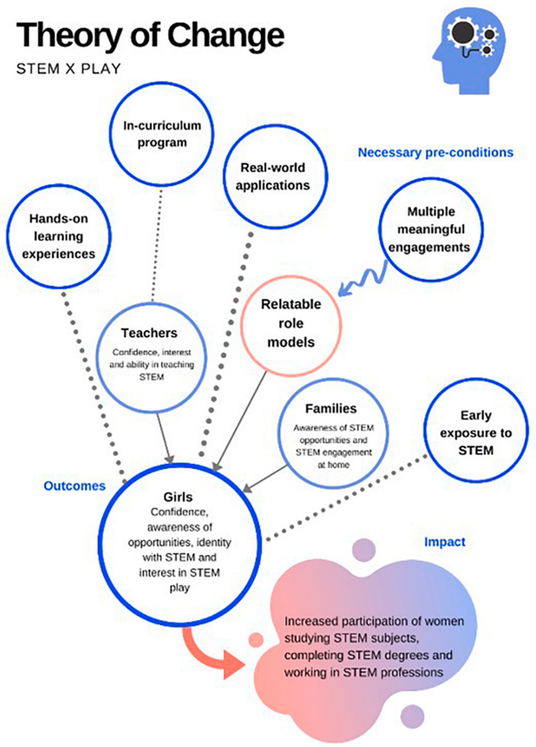

FIGURE 1
Theory of change for STEM × Play program.

3.2 The STEM × Play program structure

The program was structured on project-based learning applying the engineering design process, with curriculum content was embedded in activities to enable students' skill development. Each lesson was 1.5–2 h long to fit in with school class times and took place during the same time each week for 8 weeks.

The design problem statement (also known as the driving questions) for the projects were aligned with the Science curriculum content to ensure that the problems students chose would be related to their current term's unit of work. Students also had to use engineering and/or information technologies in their design solution and prototype. **Figure 2** presents the overall flow of the engineering design process for 8 weeks. The weekly Science curriculum content and related activities are elaborated below and presented in **Figure 3**. Examples of student projects are illustrated in **Figure 4**.

3.2.1 Empathy mapping

In week 1, students were asked to think about the issues different people may encounter as relevant to the Science unit of work. Students then drew empathy maps for a chosen stakeholder and writing down all the things that people might think, feel, see, hear, do and say.

3.2.2 Defining the problem

In week 2, students investigated and identified the problem. Defining the problem requires critical thinking about the root cause of the problem. Students started brainstorming all the problems,

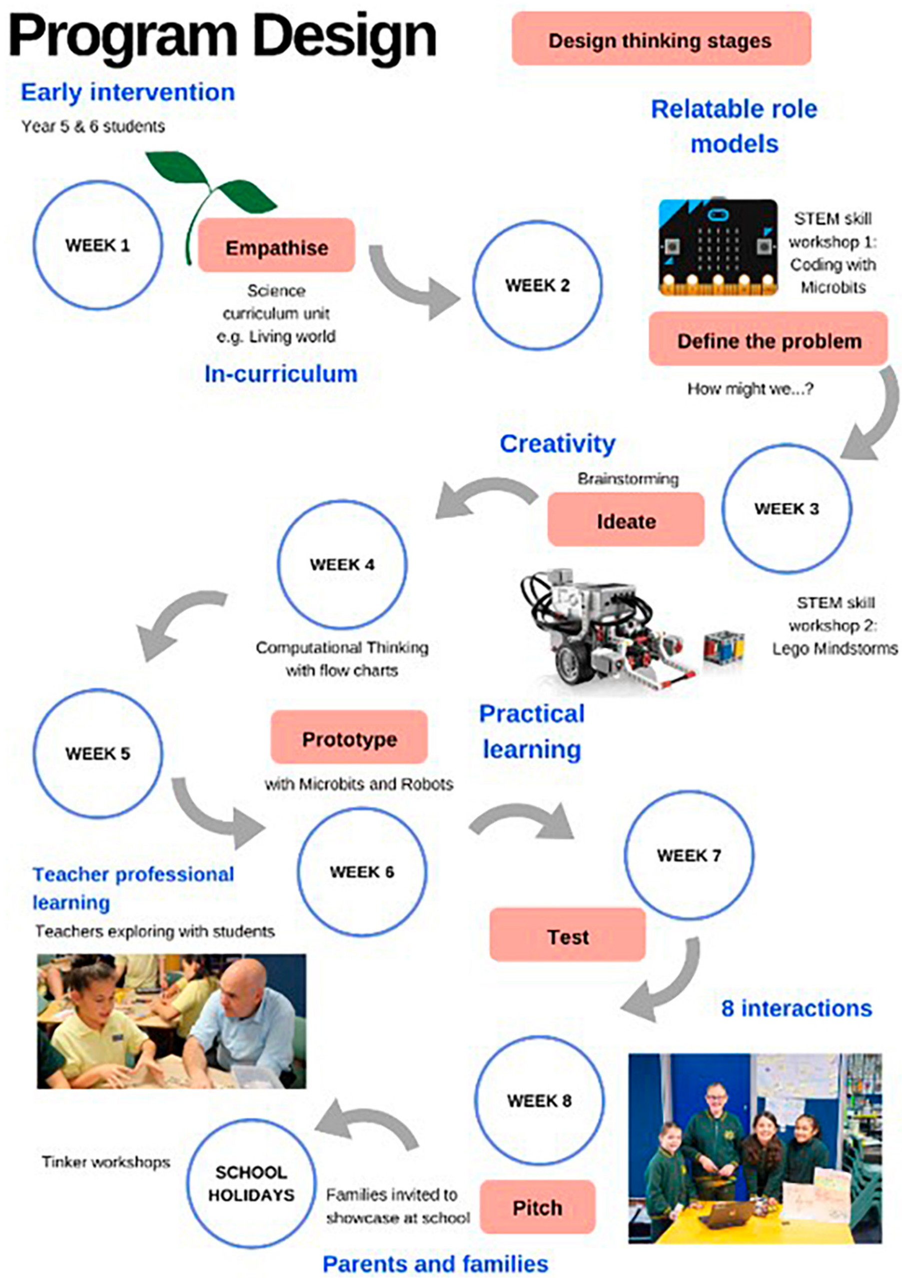

FIGURE 2
The engineering design process and weekly activity in STEM × Play.

then grouped similar ones and chose one cluster to focus on. The output of this lesson was to have a single problem statement which started with, "How might we use technology to. . ..?" The hands-on learning with various technologies began from the week 2 lesson to give students time to get comfortable with the technology before prototyping their own solutions to their design problem.

3.2.3 Ideation

In week 3, the students brainstormed solutions to their design problem using "How might we use the Microbit to . . .." The aim of the lessons was also to teach/reiterate fundamental computational thinking concepts including variables, inputs, outputs, loops and conditional statements which would allow students to create their own algorithms and logic for their design problem such as making a soil moisture sensor for farmers or a musical instrument that measured the conductivity of different materials.

3.2.4 Refine the solution

In week 4, students then developed an evaluation criteria or an "ideas checklist" to critically think about their design ideas. This helped them to decide on the solution to prototype.

3.2.5 Prototyping, testing, and troubleshooting

In weeks 5 to 7, once students had decided on a solution, they developed a flowchart with the logic of their idea. The flowcharts were particularly useful for facilitators, mentors and teachers to talk

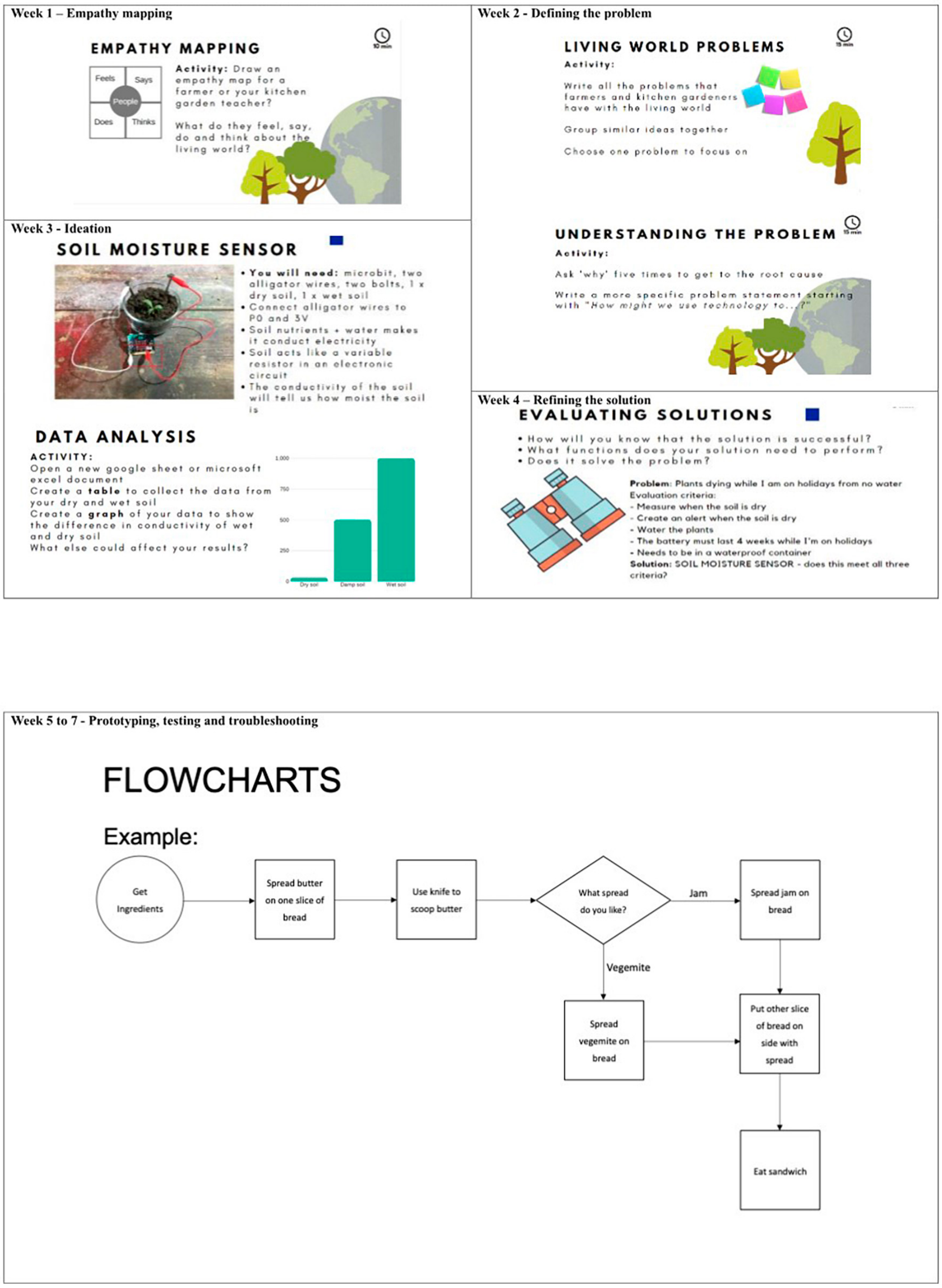

FIGURE 3
The weekly science curriculum content and related activities for week 1 to week 7.

through the students' ideas. Students needed to go through several iterations of their idea, in some cases returning to the ideation phase of the engineering design process.

3.2.6 Pitch ideas

In week 8, families, teachers and students from other grades and the school Principals were invited to the project showcase. Students set up their prototypes, similar to a Science Fair, along with all the artifacts from the engineering design process.

4 Participants

4.1 School and students

Schools selected were based on existing relationships and teacher willingness to implement the program. Five schools including 4 co-educational government schools and 1 Catholic single-sex school participated in this program. Across the five schools, 448 students (224 boys and 224 girls) from Years 5 and 6 aged 10–12 participated. Their families were well-informed of the

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Example 1
Science curriculum unit: Living World
- **End user:** Schools
- **Problem:** Rubbish in the playground
- **Solution:** Robot that detects rubbish and picks it up, alerts when it is full and puts it in the bin
- **Prototype:** Lego Mindstorm robot with ultrasonic sensor and mechanical claw

Example 2
Science curriculum unit: Material World
- **End user:** Shoppers
- **Problem:** Plastic bags breaking when carrying your groceries home
- **Solution:** as a new material for a reusable shopping
- **Prototype:** Testing the strength and elasticity of silicone using a mechanical claw made with the Lego Mindstorm

Example 3
Science curriculum unit: Material World
- **End user:** Electricity providers and home-owners with solar panels
- **Problem:** Inefficiency of solar panels
- **Solution:** Solar panels that rotate towards sun as it moves during the day
- **Prototype:** Lego Mindstorm with colour sensor that tracks light and rotates towards it

FIGURE 4
Examples of student project.

program, invited to the project showcase and into the classroom to learn alongside students during class-time. Eighteen teachers participated and all 5 principals gave their support to take part. In some schools, teachers from other grades participated in lessons for their own professional development.

4.2 Teachers and their roles

There were 18 participating teachers who played the roles as "observer as participant" and assisted in delivery of Science Curriculum content, which gave context for students to define their problems. They co-facilitated the program activities particularly in regard to student behavior, engagement and effective communication techniques, and prepared for the classroom and equipment for students' design prototyping. This co-facilitation also served as informal professional development, especially in the use of STEM technologies. The teachers also assisted in allocating class time for students to work on their projects prior to the final program showcase, and some administrative tasks such as collection of consent forms.

4.3 Families

All the families of the participating students were provided with a resource pack to start conversations about STEM at home, increase their understanding of the range of opportunities available, and information about the program, including questions to ask their children at home about their design process and project to continue the learning outside of the classroom. They were invited to join students in the classroom during project lessons and to participate in the final program showcase as an audience.

4.4 Mentors (i.e., community of practice)

The program in-classroom delivery was facilitated by 52 mentors. Among the 52 mentors, 27 were undergraduate students (of University–authors' affiliation) who were selected based on their STEM background, ability to explain concepts to primary school students, and ability to commit to 8 weeks of lessons. Twenty-five mentors were from the University and industry partners and were selected based on relationships with (University–authors' affiliation) Women in Engineering and IT, and their tertiary education area of study or professional background. The key role of mentors was to guide the students through their projects to develop their STEM knowledge in general and engineering design knowledge in particular as well as problem-solving skills. They also introduced different devices and resources (such as Microbits, Lego, ThinkerCAD and Draw.io) to the teachers and provided them support.

5 Program evaluation process

5.1 Participants

As confined by the research ethics, we were only allowed to collect data from the students, teachers and parents for this program evaluation.

5.1.1 Students

To understand the STEM perception and attitude changes of the students after engaging into an engineering design process, all the participating students were invited to complete a pre- and post-program survey. However, due to some school administrative issues, the survey response rate was less than 10%. Thus, in each school 6–7 students, who were randomly chosen and gave consents to interview, were invited to participate in a post-program focus group interview conducted at their school. A total of 32 students (17 girls and 15 boys) responded to a thematic question "how your ideas of STEM changed (if any) as a result of the program?" in the interviews. In this program evaluation, only the interview data is reported.

5.1.2 Teachers

One teacher from each school was also interviewed individually after the program. Five teachers in total were free to express their ideas around the thematic questions: "what changes in students' STEM learning attitudes you could see," "what factors contributed (if any) to changing your perception of teaching STEM," and "what you would request to keep for the next program."

5.1.3 Families

A total of 30 parents from 5 schools completed a post-program survey online, including few open-ended questions such as "what changes (if any) in your kid's STEM learning attitudes you could see," and "what key components (if any) of the program contributed to these changes."

5.2 Data analysis

Qualitative data from the student interview, teacher interview and families' responses to the open-ended questions in the online survey were transcribed using a combination of online software and manual transcription. The data were coded to the concepts including "learning outcomes of using STEM equipment," "work collaboratively," "learning about failure," "perception of learning STEM," "perceptions of STEM as problem-solving," "mentor scheme," and "community of practice" in an attempt to evaluate the students' and teachers' changes in perceptions about and attitudes toward STEM learning and teaching. Ultimately, four significant themes regarding students' perception and attitude changes and one major factor contributing to changing teachers' perception of teaching STEM were identified (see the headings and sub-headings in "6. Results").

6 Results

The organization of reporting and discussion of the results is driven by the themes/factors, that were identified and appeared significantly in the interviews and post-program online survey.

6.1 Changes in students' perceptions about and attitudes toward STEM learning

Overall, four major themes of changes in students' perceptions and attitudes were identified from the post-program focus group student interviews, teacher interviews as well as the families' responses to the open-ended questions in the online survey. The students' (a) understanding of STEM and (b) their attitudes toward failure have been altered significantly. They no longer saw STEM just as sets of science, technology, engineering and mathematics knowledge sat individually in the curriculum but integrated tools for solving real-world problems. Failure no longer frightened them away from learning new and difficult concepts but rather, as part of the learning journey that would lead them to the right direction eventually. Building on the reduction of fear about failure, (c) the students' increasing engagement in STEM activities and (d) improvement in problem solving skills were also revealed.

6.1.1 Understanding of STEM: from students' interviews

First, the students were aware that they had a better understanding of the notion of STEM, which was not only concerned about the content knowledge of science and mathematics but "more about finding solutions to different things" (Student A). They admitted that they had no idea of what STEM was at the beginning of the program but when they proceeded into the school term, they started learning that "it's got stuff to do with problem solving" (Student B) and they "could make something that could actually work in the future" (Student C). They acknowledged that the program "made science more fun instead of just learning oxygen and stuff" (Student D). Some students even declared when they first started, they "thought it wasn't going to be that fun and we [they] would just learn about science like we [they] normally do but we [they] got to build things" (Student E). Other students "thought it [STEM] was all [about] science but they do stuff with technology as well" (Student F) and "it was not just about fixing computer but it's about actual coding" (Student G). Some students did not like coding at the beginning but when the program proceeded, they "actually like[d] it a lot" (Student H). More importantly, the students eventually learnt that the programming and building things in engineering were for "finding solutions and going through the process is [was] fun" (Student I). Student J concluded that "it [STEM] was certainly fun and I (she) guess it just sort of changed it in a good way, in terms of like, it's a bit more, fun."

6.1.2 No fear about failure: from teachers and parents' interviews

The changes in perceptions and attitudes reported in the previous section were from the students' self-reflections. However, there were some deep-down changes that the students did not realize but the teachers and families who know them well could identify. "No fear about failure" was one major attitude change that both the teachers and families could clearly observe after the program. The teachers acknowledged that their "students are [were] becoming increasingly accepting of failure and recognizing it as a step to success especially when coding" (Teacher A). They were also aware that their students have developed "confidence, improved collaboration, understanding that failure is [was] the way of learning and trying again" (Teacher B) had no harm. Other teachers even noticed their students had "more engagement with the equipment and greater risk taking in their thinking" (Teacher C). Teacher D commented that the students "liked the way that they were working in groups, they like working with the actual equipment." Similarly, the parents perceived that their children were no longer avoiding experimenting and now they were "happy to attempt complex problem solving" (Parent A). Parent B was delighted with the program and made the following comment:

"I like the pack and the trigger questions." To create an understanding of the bigger picture and intent. I like the idea of getting kids comfortable with failure as opposed to, "I got it wrong." "Also prompting them to come up with questions rather than just absorbing and receiving information which is the typical academic life."

The teachers found that there were "more girls [than previous years] are [were] showing an interest and positive response to STEM activities' (Year 5/6 Teacher E)" and "now girls have [had] an understanding that engineers have many different roles depending on who they are helping" (Teacher B). Teacher A joyfully made the following conclusion:

"Our Year 5 and 6 team won the XXX competition (using Lego Mindstorms) this year too, with more girls applying than previous years."

Likewise, Parent C of a female student noticed her daughter was "now looking at failure as part of the journey to be documented and telling the story, not just the answer." Parent D happily expressed that her daughter was "doing something different, out of her comfort zone."

6.1.3 Increasing engagement in STEM activities: from teachers' interview and parents' survey

Another significant attitude change the teachers observed was the increase in engagement in STEM activities. They acknowledged that, "students who have low engagement in the classroom were engaged in the STEM activities" (Year 5/6 Teacher E). They indicated that "a lot of students accelerated their engagement particularly those who are in the lower quartile of my [their] class" (Year 5/6 Teacher B). They also realized "those in the lower quartile were able to apply themselves differently to normal and showed improvements in a variety of areas; they built up their confidence with STEM and the resources provided to them" (Teacher A). Teacher E (of Year 5/6) expressed that "a student who was injured turned up to school on the STEM day even though his parent gave him the option to stay home." Teacher C made this final comment on student engagement: "generally, the whole cohort looked forward to Fridays and they actually looked forward to that session!" Similarly, Parent E of a female student described that her daughter was "very engaged and excited about STEM and the opportunities so I [she] have bought her a STEM kit for her upcoming birthday." Parent F of a male student expressed that his son had "excitement about practical use of his invention."

6.1.4 Improvement in problem solving skills: from teachers' interview and parents' survey

Another significant change that the teachers observed was students' improvement in problem solving skills, which was out of the teachers' expectation. They also "noticed an improvement in the ability to generate and explain their ideas" (Year 5/6 Teacher E). Teacher C made the following comments regarding students solving their problem on their own:

"You have the ability to look something and then the code, for example with the robotics, the robot is not working and not doing what they thought the program actually enabled them to do and then going back and tracing back where the areas are in the code and identifying it. And I think the surprise on their face or just that self-accomplishment is the fact that they have actually solved that problem on their own and then all of a sudden, the robots' working."

Parent F also noticed this improvement. One parent expressed that she was aware of her daughter's "increased ability of critical thinking."

6.2 Teachers' perception change in teaching STEM—Mentoring and networks

One of the interview questions that explored the teachers' perception of the crucial factor for successfully integrating engineering into Science curriculum shed light into the importance of the community of practice and support from industry. All the five interviewed teachers agreed that the resources sponsored by industry, the university and the state Department of Education as well as the assistance of the project mentors were definitely the assets of the program. Teacher D gratefully expressed that "the mentors played a crucial role in guiding students through the tasks and their approachable nature and quick problem-solving skills made them invaluable in the effective running of the program." Likewise, Teacher C stated that "they [the mentors] were very hands on and engaged with students, they did really well." Teacher A of a girl school acknowledged the significant role of the female mentors and expressed: "I do think again having mentors, young women empowering young women, that's the power of this project." The teachers also recognized their knowledge and capacity in teaching STEM have been extended through working with the mentors. Teacher B made the following comment to express her appreciation:

"What would definitely keep is the mentors. That's the highlight and students being able to see and work with someone in that field that's not the teacher. That's very empowering. And the resources, can't do much without resources. And the support that you provide for students and teachers in delivering and building capacity and knowledge and understanding in our teachers really."

Teacher E further acknowledged the contribution of mentors to the success of the program:

"I think a lot of teachers that go school, uni, don't have a lot of opportunity to learn beyond the classroom, and I think that's probably the biggest problem. I think what we need to see is a lot of people from industry coming into the education profession, and improving the education profession. The National Employment Services Association of Australia has been to create just to support its existence. I think that we need to bring people from industry and from the professions that run this sort of stuff into schools and if we do that we'll kick some goals. . ..”

Making the final remark, Teacher E expressed that many science teachers had the right intentions but did not have the skillset for teaching STEM in schools. He urged the school Principals to involve mentors and role models from universities and industries in the STEM teaching process to develop teachers' relevant skillset and knowledge.

7 Discussion

The hands-on STEM × Play program using engineering design process found students' positive perception change about STEM from the perspectives of students, families and teachers. There was evidence of positive learning outcomes for students, including critical skills needed for STEM professions such as comfort with failure (including learning by trial by error), collaboration, critical thinking and problem solving. Future work could involve evaluation of students' STEM knowledge and skills.

Core to the program's design was the community of practice that provides teachers with relatable university student and industry role models and mentors that support their teaching and learning process. The mentors were found to be a key factor in leading to positive perception change about teaching STEM among the participating teachers. This was particularly evidenced in the feedback from teachers. However, the learning process of mentors, the impacts on their career as well as on the local community of practice after mentoring the school students were not investigated. In the future, mentors and the community of practice could be involved in the evaluation process.

Finally, the program aimed to build teachers' capacity to teach STEM and the results indicated that the approach of in-classroom, co-facilitation of the engineering design process as a tool to integrate STEM in primary school could help to remove barriers for teachers to trying new pedagogical approaches. Combined with the community of practice, teachers helped facilitate and managed the student learning, whilst building capacity about STEM skills and technologies with mentors' support. Evidencing this successful approach is support from teachers for continual engagement with the community of practice to support STEM learning, including extending to other year levels post-program. Based on the Theory of Change, these positive perception changes, if sustained could result in long-term impact through further engagement in STEM study and careers.

8 Conclusion

A lack of teaching and learning resources to support STEM teaching (Roehrig et al., 2012) is one of the crucial barriers to promoting STEM education in schools. To complement this program's structure around the engineering design process was university STEM student and industry project mentors, and STEM resources supported by industry, the university and the state Department of Education that helped to upskill teachers' STEM skills. Thus, future work can focus on how to better connect STEM teachers to industry and other participating and local schools so that teachers can eventually become part of the community of practice in engineering for enhancing their STEM knowledge and teaching.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by the University of Technology Sydney Australia. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

ML: Formal analysis, Writing – original draft, Writing – review and editing, Conceptualization, Investigation. EC: Conceptualization, Methodology, Resources, Writing – review and editing, Investigation.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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