REVIEW ARTICLE

Engaging High School Girls in Interdisciplinary STEAM

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ABSTRACT

Research into Australian students' science, technology, engineering, and maths (STEM) engagement has highlighted that there are comparably fewer women enrolling in STEM programs and working in STEM industries. In Australia, males make up 84% of the total population with STEM qualifications, for example, a report in 2015 found only 13% of all engineers in Australia were women. Science, technology, engineering, art, and mathematics (STEAM), an approach to STEM education that encourages interdisciplinarity, creativity, innovation, and entrepreneurship, is a strategy that has the potential to increase girls' engagement with STEM. This research investigated the impact of the STEAMpunk Girls Program, funded by the Australian Government, on high school girls' learning and their teachers' teaching experiences. The program uses project-learning and design thinking strategies to enable the girls to gain confidence in themselves as change-makers with the capacity to generate solutions to real-world problems. Using a mixed method approach, the findings indicated that teachers and students were positive about the STEAMpunk Girls' experience, with significant increases in confidence and motivation in the girls at the end of the program.

KEY WORDS: science, technology, engineering, art, and mathematics/science, technology, engineering, and maths; high school girls; interdisciplinary learning; design thinking; problem-based learning

INTRODUCTION

Research indicates that 75% of the fastest growing occupations now require science, technology, engineering, and maths (STEM) skills and STEM industries are acknowledged as crucial for Australia's economic growth and prosperity (Hajkowicz et al., 2016; Pricewaterhouse Coopers Australia, 2015). Despite this, interest and enrolment in STEM subjects appear to be on the decline among Australian students (Kennedy et al., 2014) and have led to a corresponding decrease in the number of graduates equipped for STEM careers (Pricewaterhouse Coopers Australia, 2015). The Chief Scientist's report science, technology, engineering, and mathematics: Australia's future (Office of the Chief Scientist, 2014) focused attention on STEM education in Australia and a national STEM school education strategy (Australian Education Council, 2015) aimed to lift foundational skills in STEM learning areas by developing mathematical, scientific, and technological literacy, and promoting the development of the 21st century skills of problem solving, critical analysis, and creative thinking. Curricula and teaching strategies that focus on "real-world" STEM scenarios can make material more engaging and contribute to increased levels of motivation (STEM Task Force, 2014; Timms et al., 2018).

The focus on Australian students' STEM engagement has highlighted that comparably fewer women enroll in STEM programs and work in STEM industries. In Australia, males make up 84% of the total population with STEM qualifications (Office of the Chief Scientist, 2016) and, in 2015, only 13% of all engineers in Australia were women (Stewart, 2017).

Worldwide, women are underrepresented in many of the sciences at tertiary level (Thomson, 2018). The OECD reported in 2018 that young women represent 38% of enrolments in the physical sciences, 25% in mathematics and statistics, 22% of the enrolments in engineering, and only 19% of the enrolments in ICT (OECD, 2018).

The data show that girls are less likely to engage with STEM education and therefore have a higher risk of not developing capabilities in STEM-related skills, so are more likely to miss out on the opportunities STEM-related occupations offer (Australian Education Council, 2015). To address this imbalance and to inform a national strategy to support women and girls in STEM, the Women in STEM Decadal Plan (Australian Academy of Science, 2019) was developed by the Australian Academy of Science and the Australian Academy of Technology and Engineering. The national strategy, Advancing Women in STEM, (Commonwealth of Australia, 2019) has set out government strategies to support gender equity across the STEM sector.

Some of the factors found to influence girls' participation in STEM include: Perceived self-efficacy; willingness to operate outside of "traditional" female roles; access to role models (van Aalderen-Smeets and van der Molen, 2018); perceived irrelevance of STEM curricula to girls; perceptions that engagement in STEM requires greater intelligence and is more suited to males; and girls feeling less capable than boys despite their equal or greater ability in STEM areas (Holmes et al., 2018; Hyde et al., 1990). Stereotyping of female and male roles has been found to influence girls' career

choices and can influence the development of a girl's STEM identity (van Aalderen-Smeets and van der Molen, 2018), as STEM fields tend to be regarded as more "male-oriented" (Cheryan et al., 2015; van Tuijl and van der Molen, 2016). The secondary school curriculum itself may also influence girls' choices through its demarcation of knowledge domains. Science and maths are seen as hard subjects and the arts and humanities as soft subjects (Teese, 2007). This demarcation limits the opportunity to blend "soft" skills such as creativity, innovation, and artistic ability with "hard" knowledge in STEM and contributes to gender stereotyping (Petray et al., 2019). Chapman and Vivian (2017) identified key stakeholder groups that influence the participation of girls in STEM, including family, cultural groups, peers, clubs, schools, and STEM industries but they also identified a lack of research on understanding the barriers and motivators to girls' participation in STEM in the Australian context. Broadening the boundaries of STEM by promoting the development of 21st century skills, which are seen as integral to the work of a contemporary STEM professional (Timms et al., 2018), and which have been encouraged by the National STEM School Education Strategy (Australian Education Council, 2015), may provide a context that appeals to young women, who see opportunities to engage with these aspects of STEM. Australian employers seeking to recruit employees in STEM industries consider collaborative team working ability, adaptability, and interpersonal skills to be essential skill sets, well beyond a high level of academic achievement (Callaghan, 2017).

From STEM to Science, Technology, Engineering, Art, and Mathematics (STEAM)

STEAM education merges the arts with STEM subjects for the purpose of improving student engagement, creativity, innovation, and problem solving skills (Liao, 2016; NAEA, 2016; Perignat and Katz-Buonincontro, 2019; Root-Bernstein, 2015), and to improve employability skills such as teamwork, communication, and adaptability (Colucci-Gray et al., 2017). STEAM education encourages interdisciplinarity, innovation, and entrepreneurship and often takes a student-centric approach that allows students to become contributors of knowledge and allows them to trial "outside the box" methods of thinking in a safe and supportive space (Miller and Knezek, 2013). By applying social and human contexts to the STEM domain, STEAM programs have the potential to appeal to a wider variety of learners, including the non-STEM inclined (Ahn and Kwon, 2013). STEAM education is one possible approach that has the potential to increase girls' engagement with STEM (Peppler, 2013; Wajngurt and Sloan, 2019).

The STEAMpunk Girls Program

The Australian STEAMpunk Girls program was developed to help strengthen the pipeline of Australian women in STEM by highlighting STEM study and career pathways for young women and to equip them with relevant skills and mindsets to prepare them to select and pursue these pathways. The program fostered the growth of a STEAM mindset that included STEM knowledge and skills, as well as creativity and entrepreneurship. Showing students that they had the capacity to generate solutions to real-world problems would enable them to see themselves as change-makers with the confidence to become informed and active citizens in the future.

The STEAMpunk Girls program was implemented in secondary schools at the year 7–10 (students aged 12–15) levels in the state of New South Wales (NSW) in Australia. It was led in schools by teachers who had attended a 2-day teacher professional learning (PL) program at the University of Technology, Sydney (UTS) that focused on project-based learning (PBL) and design thinking. Teachers were able to customize the delivery of the program to suit their students and school context. By combining STEM and the arts, teachers were able to design programs to develop students' disciplinary knowledge and skills, as well as their abilities as critical consumers, creative and ethically astute citizens, innovative designers, good communicators, and collaborative decision-makers. STEAM education provided a creative design space for teachers in different learning areas to collaborate in developing integrated curricula. Using a PBL approach, students had to use creative and innovative thinking to come up with a product or program integrating concepts from across STEAM disciplines. Schools were also able to access UTS resources like guest speakers and student mentors to provide role models for their students.

Design Lab Teacher PL Program

Design Lab was a NSW Education Standards Authority accredited 2-day PL program, during which teachers learned about the elements of STEAM, PBL, and design thinking. They used empathy surveys that they had been asked to carry out with their students before the PL, to develop a driving question for their student project. By working through the five stages of design thinking: Empathize; define; ideate; prototype; and test, the teachers constructed a design plan and strategy to deliver the program in their particular context. Thus, the PL program modeled the processes that the teachers would follow with their students and that the students would employ during their own projects. The teachers were also made aware of opportunities to engage with personnel and resources from the university and industries to enhance their project and to provide role models and inspiration for their students.

Key Parts of Each Project

The key parts of projects developed based on PBL are shown below, with parts 2–6 representing the five stages of design thinking:

1. Hook event – Introduction of the program to generate interest and enthusiasm among students
2. Empathize – Students conducted research to understand user needs
3. Define – Students defined what the problem was
4. Ideate – Students used their empathy work to generate a range of creative solutions quickly
5. Prototype – Students modeled and built prototypes of best ideas

6. Test – Students presented their prototypes to each other and got feedback
7. Showcase – Students pitched their project to classmates, teachers, family, community members, etc.

RESEARCH QUESTIONS

The research sought to answer the research question: What has been the impact of the STEAMpunk Girls program on the teaching and learning experiences of secondary school teachers and female students? Specifically, what has been the impact of the program on:

- Teacher and school capacity in PBL, design thinking, and STEAM?
- Students' learning preferences in terms of PBL and design thinking?
- Students' self-efficacy in STEM?
- Students' intentions of studying STEAM subjects in higher education? and
- Students' beliefs in and aptitude for STEAM careers?

METHODOLOGY

The research design used a mixed methods approach to investigate the impact of the program on the learning and teaching experiences of high school students and teachers. The research employed quantitative online survey methodologies as well as qualitative methods of focus group.

Participants

Participants were secondary school teachers, who took part in the Design Lab STEAMpunk Girls PL program, and their students, with whom they implemented a project that they devised during the PL. Overall, 89 NSW teachers (51 metropolitan and 38 regional) attended the university for the PL program and 352 female students (189 metropolitan and 163 regional) students participated in STEAMpunk Girls projects in their schools. The total number of schools that participated in the program was 25. Ethics approval was obtained from the university and Department of Education's Human Ethics Committee prior the start of the research. Approved consent forms that indicated voluntary participation in the research was sought were distributed to the teachers and students before data gathering in respective schools. Fourteen schools consented to participate in the research. Only those teachers and students who brought back signed consent forms were interviewed and the teachers' teaching observed. Informal conversations during class observations were only conducted with students who have consented to be part of the research.

Research Instruments

Pre- and post-project online surveys collected data from teachers on the impact of the program on capacity in PBL, design thinking, and STEAM education. The pre- and post-surveys consisted of a common set of Likert-style statements, with a five-point scale. The post-project survey also contained additional Likert-style items concerning perceived effects of the project on students. The teachers' post-project

survey also contained a number of open response questions about their experience of the project. Focus group interviews were conducted with teachers at the commencement of the 2-day teacher PL program. These focus groups collected data about the teachers' current STEM teaching practices and their expectations of the STEAMpunk Girls project. Post-project interviews were conducted with teachers in nine schools about their perceptions and experiences of the program.

Students completed online surveys before and after commencement of their STEAMpunk Girls project. The surveys comprised Likert-style statements, with a 5-point scale, and collected data about students' awareness and motivation for engaging in STEM subjects and their interest in and knowledge of STEM career paths. The post-project surveys contained additional Likert-style items and open response questions concerning the students' experience of the project. Focus group interviews were conducted with students at nine schools at the conclusion of the project. These schools were selected to represent the range of school demographics in the state of NSW where the research was conducted. The focus groups collected data about students' perceptions and experiences of the program.

Researchers also observed the implementation of the STEAMpunk Girls project in the nine selected schools and field notes were taken. This wide range of data collection methods provided rich data for case studies of the project implementation in those nine schools.

Data Analysis

Quantitative data from teacher and student pre- and post-project online surveys were analyzed using the statistical package SPSS v25. t-tests were conducted to detect differences between pre- and post-test data. Teacher and student focus groups and interviews were audio recorded and field notes were made during observations. The audio recordings were not transcribed. Qualitative data from the open response survey questions, the focus group interviews, and the observations were manually coded and analyzed by the researchers using excel. All data sources provided rich information for the case studies.

FINDINGS

Results are presented from the 17 teachers and 53 students, whose pre- and post-project surveys could be matched, as shown in Table 1. Including only matched surveys in the analysis allows for more reliable pre- and post-test data comparison.

The lower number of participants responding to the pre- and post-surveys is due to the fact that participating in the

Table 1: Number of valid survey responses

Participant	Pre-project	Post-project	Pre-post matched
Teachers	45	21	17
Students	172	72	53

research was voluntary. Only 14 schools formally consented to be involved in the STEAMpunk Girls Project's research. Another reason for the relatively low-matched responses is that some participants had forgotten their pre-survey identification code, resulting in mismatches between pre- and post-survey responses. Of the 14 participating schools, the researchers visited nine schools, observing the project implementation, attending showcase events, conducting student focus groups, and interviewing teachers. These schools became case study schools, although the details of the case studies are beyond the scope of this paper to present.

Design Lab teacher PL program

Pre-program focus group interviews asked the teachers what they were expecting to gain from the gender targeted project. All of the responses to this question mentioned gaining more knowledge of PBL and ideas to implement STEM/STEAM with their students. When asked about the PL program in the post-project survey, the teachers' responses indicated that these expectations had been met. What they valued most was being able to work through the design thinking process themselves. They also valued the interaction with, and feedback from, fellow teachers. Some comments included in the study:

- I found all aspects of the workshop useful by effectively giving students the opportunity to engage in STEM and developing my own teaching practice, with particular focus on design thinking, which I can apply to my teaching practice. I valued the support and feedback from the presenter and my fellow colleagues. The workshop was intensive and had purpose, I went away feeling confident in delivering to program to not only the STEAMpunk Girls but to my classes. Both days were useful, what I really liked was the design thinking process that allowed us to create our school PBL
- Creating and designing our own projects was great. Sharing of knowledge and resources
- Listening to the women who were actually working in the field/industry. How to implement project based learning, and going through the process ourselves
- Designing and critiquing programs to be run in the school
- The interactive feedback of other teachers during the project designing.

Some examples of driving questions for projects that the teachers developed during the professional leaning program were:

- How can we limit the effects of climate change on our school?
- How can young women be pioneers in technology?
- How do we create a space that sparks joy?
- How can we improve our water usage at school?
- Can our school's trash be treasure?
- How can we survive a drought?
- How can we, as innovators, create more sustainable trends?
- How can our school reduce its environmental footprint?
- How can we use the environment to create art?
- How can technology improve relationships?

- How can we, as designers, design a product to help a student with a disability to access our school?

Teacher Participants

Of the 17 teachers who completed matched pre- and post-project surveys, 82% were female and 18% male with 76% of them from government school and 24% from non-government schools. Most of the teachers (76%) were from co-educational schools and 24% from single-sex (girls) schools. Figures 1 and 2 show the main subjects taught by each of these "matched" teachers and the teachers' years of teaching experience, respectively. Nearly 60% of the teachers taught science and just over 10% taught mathematics, English or human society and its environment. Only 18% of the teachers had taught for <5 years, with 41% having 5–10 years and another 41% having more than 10 years of teaching experience.

Teachers' Self-efficacy in PBL, Design Thinking, and STEM/STEAM

Figure 3 shows the mean values of the teachers' pre- and post-project survey responses regarding their understanding of and confidence in PBL, design thinking, STEAM, and
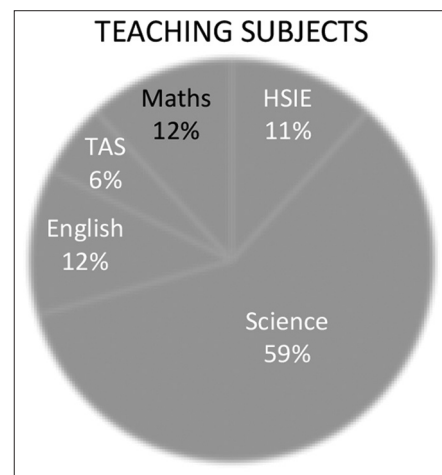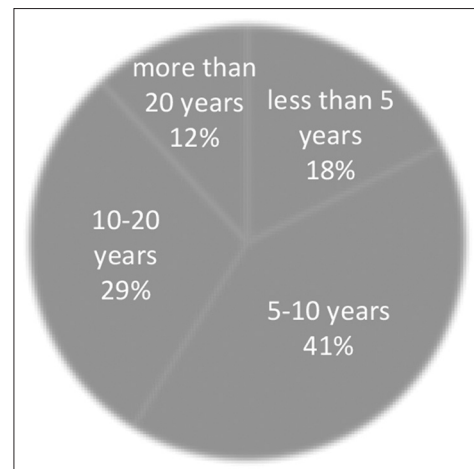

Figure 1: Main subject taught

**Figure 2:** Years of teaching experience

STEM. The lowest pre-project mean values, indicating the areas of least understanding among the teachers before the project, were for the items "I have a good understanding of Design Thinking" (M = 2.82) and I have a good understanding of STEAM teaching strategies' (M = 2.76). Both values are below the midpoint of the scale (M = 3.00). All mean values for post-project survey items had increased and were higher than the pre-project means. Teacher confidence in their ability to engage and motivate their students in STEM was relatively high before the project with both items of "engagement" and "motivation" having mean values of 3.82, but these had increased by the end of the project (M = 4.35 and M = 4.06, respectively, although the motivation item difference is not significant). Teacher understanding of PBL was also relatively high pre-project (M = 3.76) but had also increased

post-project (M = 4.53), to be the highest mean value of all the survey items.

There was a significant difference at the 95% confidence level between the pre- and post-project mean values of all except two of the survey items, as shown in Table 2.

Teachers' Perceptions of the Impact of STEAMpunk Girls' Program on their Students

The mean values for all survey items about teachers' perceptions of the effect of the STEAMpunk Girls project on their students were well above the midpoint of the scale (M = 3.00), as shown in Figure 4. The highest mean value (M = 4.65) was for the item "Participating in the STEAMpunk Girls project was an enjoyable learning experience for my students." The lowest mean value (M = 3.59) was for the item
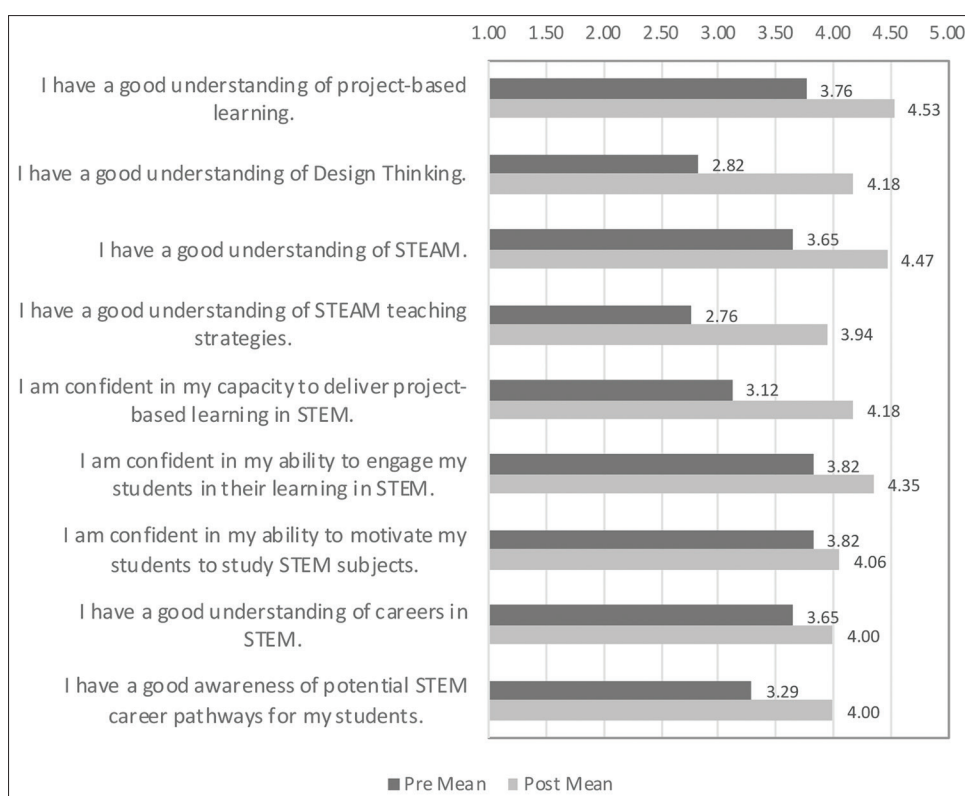

Figure 3: Teacher post-project mean values for items relating to project-based learning, science, technology, engineering, art, and mathematics and science, technology, engineering, and mathematics

Table 2: Results of paired samples t-test on teacher pre- and post-project survey items

Survey item	Pre-test M	Pre-test SD	Post- test M	Post- test SD	Sig.
I have a good understanding of PBL	3.76	0.56	4.53	0.51	0.00
I have a good understanding of design thinking	2.82	0.81	4.18	0.39	0.00
I have a good understanding of STEAM	3.65	0.79	4.47	0.51	0.00
I have a good understanding of STEAM teaching strategies	2.76	0.66	3.94	0.56	0.00
I am confident in my capacity to deliver PBL in STEM	3.12	0.78	4.18	0.53	0.00
I am confident in my ability to engage my students in their learning in STEM	3.82	0.39	4.35	0.70	0.00
I am confident in my ability to motivate my students to study STEM subjects	3.82	0.73	4.06	0.66	0.26
I have a good understanding of careers in STEM	3.65	0.61	4.00	0.61	0.03
I have a good awareness of potential STEM career pathways for my students	3.29	0.77	4.00	0.71	0.00

STEM: Science, technology, engineering, and maths, STEAM: Science, technology, engineering, art, and mathematics, PBL: Project-based learning
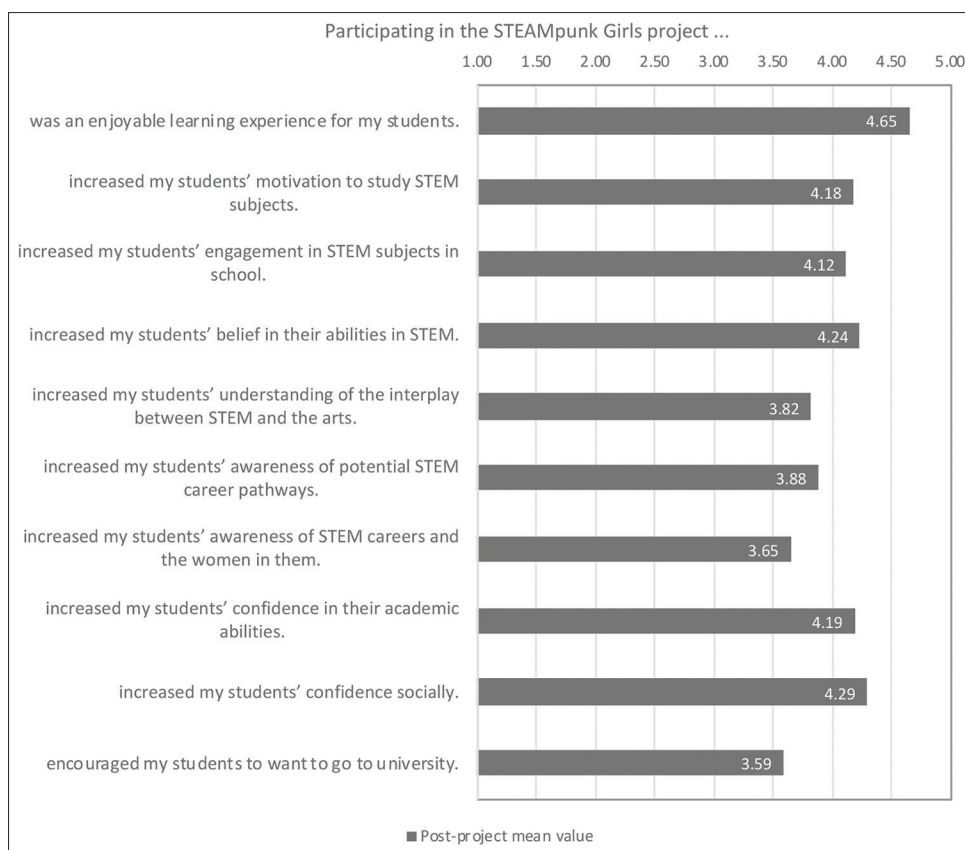
Figure 4: Mean values of survey items concerning teacher perceptions of the effects of the STEAMpunk Girls project on their students

"Participating in the STEAMpunk Girls project encouraged my students to want to go to university."

The teachers' open survey responses about what their students gained from the project supported the quantitative results represented in Figure 4. They considered that their students had gained skills in teamwork and collaboration as well as creative problem-solving. They mentioned that the students enjoyed the authentic nature of the project. Typical comments included in the study:

- Through their work, students learnt that what they were doing had purpose and they were excited and engaged with the potential of STEM
- Students feel their opinions are valued and can enact change. Students think the project is "fun" Focus on empathy. Focus on developing for a real audience. Students liked realness of the project.

The teachers were very positive about the project in the post-project teacher survey. Some of their comments included in the study:

- Thank you for this opportunity. STEAMpunk Girls has been an amazing experience and will continue to support our girls in STEM careers. It has the potential to reach so many in our school community because it is accessible and open to teachers with all levels of expertise
- Have really enjoyed being a part of this program and will continue it with the girls further

- A strong confidence building activity that has given me confidence to implement project based learning in my mainstream classes
- It was a fantastic program – we will take the skills from this program to create others that will run throughout the year. Already, the boys are asking when is it our turn. We have confidence that we can ask for help/guest speakers from UTS through the connections established from this program and we are very grateful to have had this opportunity.

When asked about any challenges they faced during the project, most of the issues raised by teachers were about fitting the project into the school's existing structure and timetable. Some examples of comments were:
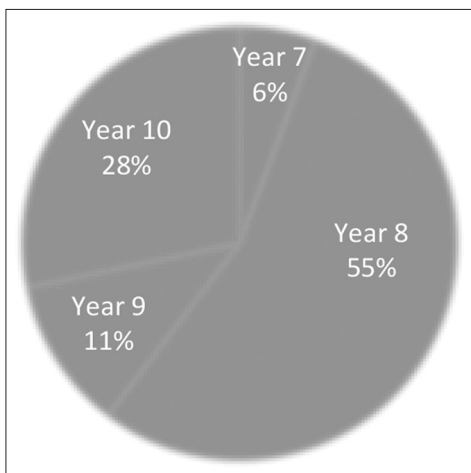
- TIME – we had to run the program during 1 lunch each week – we really needed at least half day each week to really get the most out of it
- Small class size meant lack of "momentum." Initial idea to do across year 8 maths was too difficult to get three teachers working together in such a core subject. More time needed to be allocated to preparation of unit
- Some of the girls were opposed to participation in the STEAMpunk Girls program because it ran in place of other lessons and so they "fell behind" in those subjects. It would help to be able to run the program as an additional project (before/after school or as a separate course)
- Timing of the project and being able to get the all students to be consistently present during the project.

Impact on Students: Student Participants

The 53 students who completed matched pre- and post-project surveys ranged from year 7 students to students in year 10, with most of them in year 8, as shown in Figure 5. Forty-one percent of these survey respondents attended co-educational government schools and 59% attended non-government girls' schools.

## Impact of STEAMpunk Girls' Program on Students' Learning Preferences in Terms of PBL and Design Thinking

The students were asked about their learning preferences before and after the project. They were asked to rate their agreement with a number of statements on a five-point scale. As shown in Figure 6, the statement with the highest mean value or highest level of agreement was "I like to learn by doing" (pre-M = 4.30, post-M = 4.11). The next highest mean value was for the statement "I can do anything if I put my mind to it and work hard" (pre-M = 4.21, post-M = 4.15), followed by "I like to see the "real world" impact of what I learn at school" (pre-M = 4.17, post-M = 3.98) and "I like being creative" (pre-M = 4.13, post-M = 4.00). All statements attracted agreement at levels above the midpoint of the scale, however, the lowest mean value (pre-M = 3.26, post-M = 3.45) was for the statement "I like working on projects alone." The increase in mean value in the post survey indicates that there are some issues in team work that teachers should be aware of in PBL. This is further supported by the decrease in mean value (pre-M = 4.06, post-M = 3.85) of "I can make a valuable contribution in a team" where some of the students did not think that they made a valuable contribution to the team and would rather work alone.

A paired samples t-test was conducted to determine whether there was a statistically significant difference between the pre- and post-project responses about students' learning preferences. No significant differences were detected. Nevertheless, for the items "I like to solve problems" and "I like to combine knowledge and skills from different fields to solve problems," the mean values were increased in the post-survey (pre-M = 3.70 and post-M = 3.75 for the former statement and pre-M = 3.83 and post-M = 3.96 for the latter statement). It indicates that these aspects of the STEAMpunk

Figure 5: Year levels of matched pre-and post-project student survey participants. (n = 53)
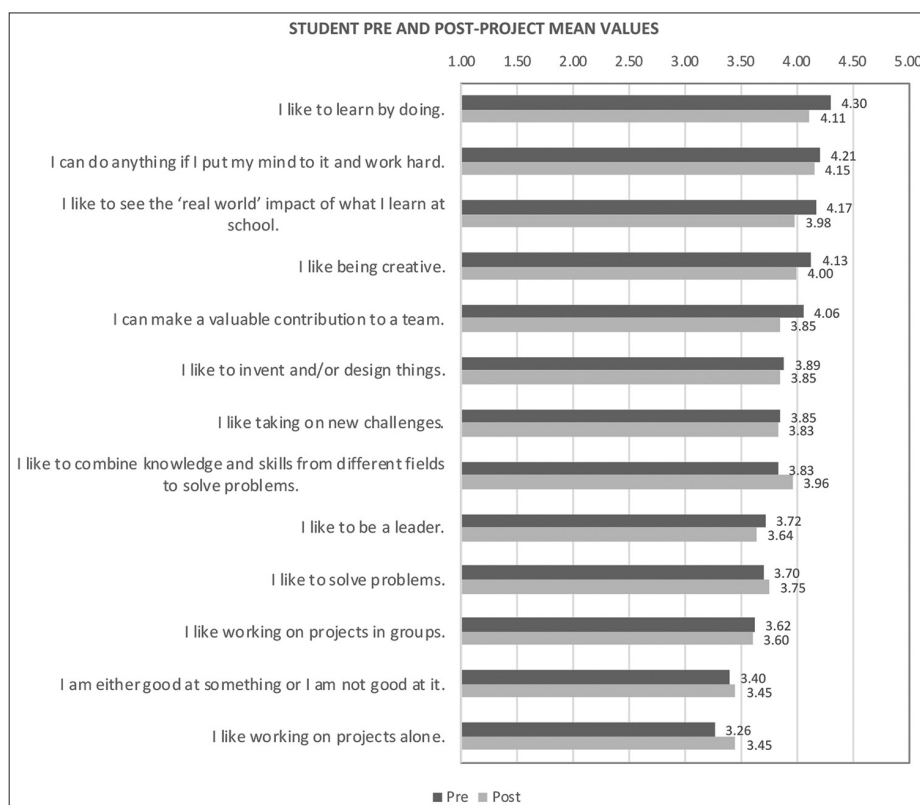
Figure 6: Mean values for statements about students' learning preferences

Girls project impacted positively on the students. However, it should be noted that many of the projects were of short duration (usually less than a 10-week term or were lunchtime or after school programs), and impact of PBL and design thinking may be more accurately measured over 2–3 iterations of the program. This should be the focus for future research.

Impact on Students' Self-efficacy in STEM

The girls' confidence, interest, and ability in STEM were evaluated at the end of the project. As shown in Figure 7, the mean values for all survey items about students' perceptions of the effects of the STEAMpunk Girls project were above the midpoint of the scale (M = 3.00), indicating positivity in the items investigated. The highest mean values were for the items "Participating in the STEAMpunk Girls project increased my awareness of STEM careers and the women in them" (M = 3.81), "Participating in the STEAMpunk Girls project was an enjoyable learning experience" (M = 3.75), and "Participating in the STEAMpunk Girls project helped me learn problem solving strategies" (M = 3.71). The girls were also positive about their ability in STEM (M = 3.68) with increased motivation to study STEM subjects (M = 3.51) and increased confidence in: Academic abilities (M = 3.49); creative abilities (M = 3.42); and ability to work positively in a team environment (M = 3.55).

In the post-project survey, themes that emerged from students' comments about what they gained from the project were:

i. Skills in teamwork, collaboration, and creative problem-solving, for example:

- I gained an understanding of working with a team. And coming up with ideas by listening to each other
- I gained a better understanding of the problem-solving process used to create inventions
- I gained the ability to work as a team under time pressure
- I understand how to think outside of the box, brainstorm efficiently, and utilize my time wisely to figure out all the components of my project to then demonstrate these components.

ii. Gain in confidence, for example:

- I got to know about things that I previously did not know and I was not confident to speak out to other teachers or students out of my group – so I gained confidence in doing this
- I learnt that through the STEAMpunk Girls project that we are capable of doing anything we put our minds to.

iii. Enjoyment of authentic learning and real-world projects, for example:

- I got more interest in STEM projects and have learnt a lot about droughts and how we can make an invention to help an issue
- Working as a group to help people in our wider community.

iv. Learning about women in STEM, for example:

- I learned that STEM offer many career pathways and is the future-generation
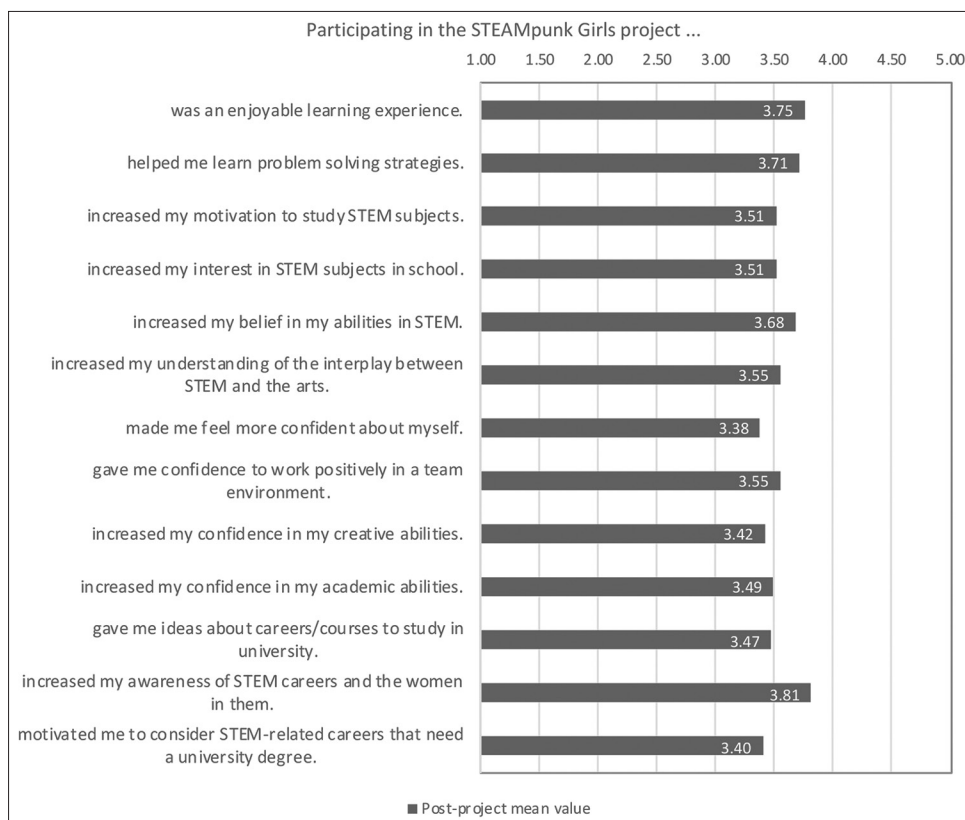- I learnt that woman are capable in all STEAM subjects

Figure 7: Post-project mean values for student perceptions of the impact of the STEAMpunk Girls program

- Learn about how capable women are in STEM, not just men.

Impact on Students' Intentions of Studying STEM Subjects in Higher Education

Students were asked in pre- and post-project surveys to indicate the subjects (Arts/Humanities and STEM subjects) that they would consider studying in higher education. Figure 8 shows that the students were most likely to consider studying Arts/Humanities at university both before and after the project. In STEM subjects, the most popular area for likely study was science, with an increase of 9% of students considering studying in this area in the post-project data. A noteworthy result is the largest increase in percentage of students considering studying IT/Tech, an increase of 11% points. These increases in interest in tertiary study of science and IT, however, were not statistically significant according to a McNemar Chi-square test (Adedokun and Burgess, 2012). The post-project data for engineering and mathematics subjects showed a decline in the percentage (about 6% and 2%, respectively, but not statistically significant) of students who would consider studying these subjects at university. A possible reason for the decline is that mathematics and engineering were not explicit to the students in the projects that they were involved in. Students have little understanding of engineering content or the nature of engineering studies since the discipline is not offered in schools. Teachers would need to teach engineering concepts and engineering applications explicitly, as well as mathematics applications, in PBL.

Impact of the Program on Students' Beliefs about and Aptitude for STEAM Careers

Student Beliefs about STEAM Occupations and Barriers to Women

Students were asked to indicate whether they had a good understanding of the kind of work involved in STEAM fields. As shown in Figure 9, in the pre-project surveys, students felt that they had most understanding of the work people do in the Arts/Humanities and least understanding of work in engineering. After participation in the project, student understanding of the kind of work involved in all the occupations had increased substantially There was an
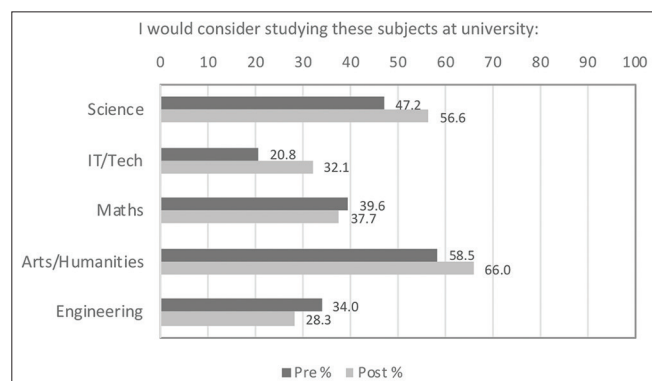
increase of 15% points in students' perception that they had a good understanding of what people do who work in science and engineering, 13% points in IT and eleven points in mathematics. However, none of these differences were statistically significant. The post-project data showed that students' understanding of science careers had increased to the same level as the Arts/Humanities.

When the girls were asked about barriers for women working in STEAM occupations, they believed that there were fewer barriers for women working in the Arts/Humanities (23%) and mathematics (30%), as shown in Figure 10. Before the project, 76% of the students believed that there were barriers for women working in engineering, 57% believed there were barriers for women working in IT/Tech industries, and 42% believed that there were barriers in science. In the post-project survey, the percentage of students holding these beliefs had diminished substantially, with only 40% believing there were barriers in engineering, a decrease in 36% points. This was a statistically significant difference ($\rho = 0.000$), according to a McNemar Chi-square test (Adedokun and Burgess, 2012). Likewise, there were decreases in students' beliefs that there were barriers to women working in IT/Tech of 29% points in IT/Tech (a statistically significant difference [$\rho=0.006$]) and 12% points in science. It appears that the exposure to female STEM role models had a positive impact on the girls participating in the program.
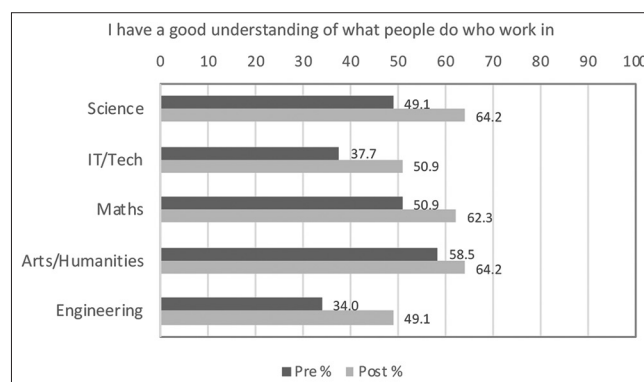

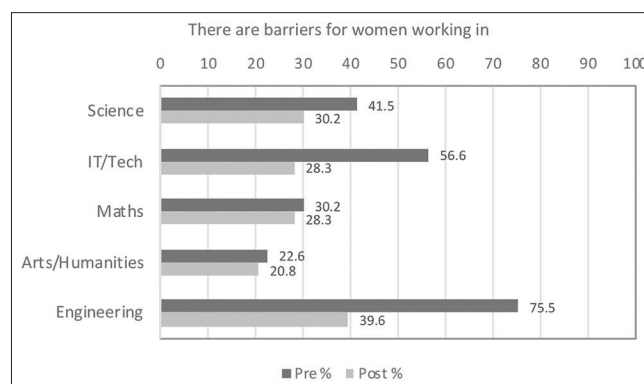**Figure 9:** Percentage of students' understanding of STEAM occupations

Figure 10: Percentage of students' beliefs about barriers for women working in STEAM occupations

Figure 8: Percentage of students' intentions to study at university

Aptitude for STEAM careers

As shown in Figure 11, students' perceptions about their ability to work in STEAM fields indicated that, before the project, the largest number of students (59%) considered that they had what it takes to work in the Arts/Humanities, followed by science (51%). In the post-project survey, there was an increase in the percentage of students who felt that they had what it takes to work in all of the STEAM areas. There was an increase of 17% points in students' beliefs that they had what it takes to work in engineering, 15% points increase in science, nine points in IT, and six points in mathematics. Although substantial, these increases were not statistically significant. The STEAMpunk Girls program appears to have made substantial impact on building the confidence of the girls in STEAM careers.

DISCUSSION

The research sought to investigate the impact of a girls-only focused initiative on secondary female students across school sectors and socioeconomic backgrounds. The nature of this project, being only for girls, led to great diversity in school implementation strategies. In single-sex schools, teachers adopted the following models: Applying PBL and the design thinking process to units of work in regular classes and meeting syllabus outcomes; working with one class to develop the driving question in all the STEAM disciplines over a number of weeks; and withdrawing a group of students to undertake the project. Co-educational schools had the challenge of what to do with the boys during the project. Some schools provided alternative activities for the boys and ran the project during regular class time. In other schools, the program was either offered outside of class time, during lunchtime or after school, or during class time by arrangement with other teachers. In these circumstances, the project group size was usually quite small.

The Impact of the Program on Teachers

The impact of the program on teachers and school capacity in PBL, design thinking, and STEAM was very positive, according to paired samples t-tests carried out on pre- and post-project quantitative data where it is shown that the project made a statistically significant difference to teacher capacity
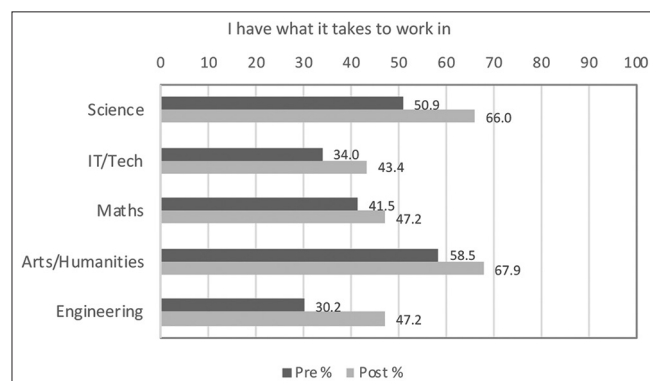

Figure 11: Percentage of students' aptitude for STEAM occupations

in these areas. This was confirmed by the qualitative survey data from interviews and observations. The teachers found the 2-day PL program to be very effective. It stepped them through the design thinking process so that they experienced all of the stages while developing their own project and driving question. They found that this helped them to implement the project with their students.

Many of the teachers who attended the PL had had little experience with PBL before the project and appreciated the practical, hands-on approach. Most teachers were unfamiliar with the design thinking process and many of the teachers who had used the design process before were not familiar with the significance of the empathy stage, which was an important step in ensuring the investment of the students in their project and giving them a sense of ownership of it.

The nature of the project that focused on interdisciplinary science, technology, engineering, arts and mathematics (STEAM) drew a substantial number of teachers, who were not from STEM disciplines, to attend the PL program because they were interested in working with STEM subject teachers from their schools to develop a STEAM project. This collaboration between teachers of different disciplines was considered one of the most valuable parts of STEAMpunk Girls according to the teacher surveys and interviews. Teachers commented that they had little chance to work with colleagues in other subject areas during the normal course of school life and many found that there was much common ground in the Key Learning Areas (KLAs).

Many of the teachers indicated in the surveys and interviews that they would run the project again by "using the skills from this program to create others that will run throughout the year."

For some of the teachers, the STEAMpunk Girls initiative was an introduction to PBL and a chance to "dip a toe in the water" with a small group, to consolidate their skills and apply them in their classrooms in the future. For others, it was an opportunity to collaborate with teachers in other KLAs to develop multi-disciplinary projects that could be adapted and expanded in the future. For still other schools, it was an opportunity to begin to build a STEAM community in the school. In all cases, according to the teachers, the project was judged to have improved teacher and school capacity in PBL, design thinking, and STEAM.

The Impact of the Program on Students

In the pre-survey, many of the girls who were involved in STEAMpunk Girls did not consider STEM subjects to be their favorites. However, the students enjoyed the STEM aspects built in to their STEAMpunk Girls projects. Some students mentioned that they now liked science whereas they had thought it was boring in the past (Holmes et al., 2018; van Aalderen-Smeets and van der Molen, 2018). Other students commented that they had become involved in the project because they wanted to experience subject areas that they did not know very much about and see whether they sparked their

interest (Kang et al., 2019). Other students appreciated that they could experience STEM subjects that were traditionally seen as "boy subjects" in a safe and supportive all-girls environment (Cheryan et al., 2015; van Tuijl and van der Molen, 2016). This aspect of the project seemed to be important for many of the girls. There were many comments about the boys "trying to boss them around," "thinking they were better," "not helping" them, and "not taking things seriously" in their STEM classes. STEAMpunk Girls provided a space for students to experience STEM subjects in combination with activities that they had previously associated with, and were more familiar with, in Arts/Humanities subjects. For many this made them feel more comfortable with STEM subjects, which they had previously seen as "*technical*" (Peppler, 2013; Wajngurt and Sloan, 2019).

One of the notable findings of the research is that, by explicitly exposing the girls to PBL and design thinking, the girls in the program showed an increase (although not statistically significant) in their interest in problem solving, particularly with the authenticity of the real-world problems that they all worked on (Colucci-Gray et al., 2017). There is, however, some indication that teamwork may not have worked so well with some of the girls, as there was an increase (not statistically significant) in the number of responses in the post-project survey for a preference to work alone. The role of the teachers as facilitators of PBL, where collaboration is a central feature, is to ensure that issues within groups are identified and resolved quickly.

The STEAMpunk Girls' Program was an enjoyable, authentic learning experience for the vast majority of the girls. They believed that the experience increased their confidence in academic and creative abilities as well as their ability to work in a team environment. They made gains in collaborative skills as team members and creative problem-solving skills in solving community-based problems that they identified for their projects. They also highlighted that they had increased their awareness of STEM careers and the women in them. These experiences would enhance their interest and motivation in STEM subjects and STEM-related careers, which would contribute to addressing the national issues of the inadequate supply of women in STEM careers (Australian Education Council, 2015; Colucci-Gray et al., 2017; Timms et al., 2018). The data in the research show that there were substantial (but not statistically significant) increases in the students considering studying science and IT after the project, although mathematics and engineering subjects showed a small (but not statistically significant) decrease in the students' consideration to study these subjects in higher education. The implication here is that more attention is required to make explicit the mathematical and engineering aspects of the PBL, which were usually not immediately evident in the community-based projects that the students engaged in. In addition, schools should teach engineering concepts to girls in schools and involve women role models in STEM careers on a regular basis to engage and motivate the girls. This will further enhance the students' understanding of the kind of work involved in STEM careers and possible barriers for women working in

STEM (Falco and Summers, 2019; Herrmann et al., 2016) – these elements showed substantial increases and decreases, respectively, after the project. The data showed a statistically significant decrease in the girls' perceptions of barriers existing for women working in engineering and IT careers.

The strong positive overall impact of the STEAMpunk Girls' Project on the students is evident from the substantial increases in their perceptions about their ability to work in all S, T, E, A, and M fields in the post-project survey. Increases of 6–17% points were shown for these fields, indicating confidence in the students' own ability to work in these areas.

CONCLUSION

Research findings from the STEAMpunk Girls Program reported in this study demonstrate the utility of employing a PBL educational approach in high school classrooms and the potential benefits of using an interdisciplinary STEAM approach to motivate and engage girls in STEM education and in the longer term, STEM careers (Colucci-Gray et al., 2017; Peppler and Wohlwend, 2017; Perignat and Katz-Buonincontro, 2019; Wajngurt and Sloan, 2019). The teachers found the PL program on PBL and design thinking to be very effective. The program identified important influences on young women's study and career pathways, underlining the value placed on personal interest, the potential for creativity, and social values like friendship (Dasgupta and Stout, 2014; Harris and de Bruin, 2018). The positive findings from the program, especially in relation to an increased understanding of STEM fields, highlight the ability of programs such as STEAMpunk Girls to improve young women's interest in and knowledge of STEM careers (Chapman and Vivian, 2017).

The findings contribute to existing research about STEAM education and provide guidance to educators implementing cross-disciplinary education or working to empower young women to think innovatively and feel confident in their capacity to study STEM subjects and take an active role in their world (Liao, 2016; Nation et al., 2019; Perignat and Katz-Buonincontro, 2019; Walan, 2019). It also presents a model that can be replicated at any level of education, from primary schools to higher education.

One of the implications of the research is that schools should provide girls with opportunities to engage in STEM/STEAM interdisciplinary learning using the core strategies of the STEAMpunk Girls Program that embraces design thinking and problem-solving activities through PBL. Another implication is that girls in co-educational schools would benefit from being given opportunities to work on projects in a girls-only environment, for example, through withdrawal or extra-curricular programs. A third implication is that school-aged girls should be frequently exposed to female STEM professionals and STEM student mentors as role models to build their interest and motivation in STEM-related careers. These strategies could contribute to increasing the pipeline of women STEM professionals in the nation.

ACKNOWLEDGMENT

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