Design and Evaluation in STEM outreach: a case study of a High School Program to increase female participation

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ABSTRACT

CONTEXT

A pervasive lack of female participation in STEM secondary school subjects and tertiary degrees in Australia continues to contribute to the ongoing inequity in representation within STEM professions. Attitudes and interest for the study of STEM are largely formed by the age of 14, with these factors declining earlier for girls compared to boys. Various initiatives have been developed to encourage secondary school girls' engagement with STEM subjects.

PURPOSE OR GOAL

The aim of the present paper is to describe the design and evaluation of a 10-week STEM outreach program delivered in secondary schools to 200 girls (aged 13-16 years) in the Hunter Region of New South Wales, Australia. The program design is informed by relevant research literature suggesting the value of mentorship in fostering a STEM identity and addressing negative stereotypes. The program includes three main components: 1) Weekly workshops with female university mentors (where students identify and design STEM solutions to community issues); 2) Industry or University site visits (to demonstrate what STEM careers look like in practice) and 3) Final presentations (where students showcase their STEM solution to local industry members).

APPROACH OR METHODOLOGY/METHODS

Pre- and post- program survey data were collected from participants (N=154) each year the program ran (2017-2019) to evaluate impact on STEM identity. Survey items related to students' experiences with the program, and their female mentors specifically, were also included in the post-program survey. Survey responses were analysed using inferential statistics (t-tests).

ACTUAL OR ANTICIPATED OUTCOMES

A range of community issues (e.g., pollution clean-up and mental health) and solutions (e.g., physical prototypes and mobile phone applications) were identified and developed by participants. Statistically significant improvements were observed in participant attitudes on several scales relating to understanding the scientific method, understanding usefulness of science, and improving awareness of STEM careers. Participants demonstrated a high level of satisfaction with the program and their female mentors, exemplified by a high level of agreeance (on a 4-point scale from 'strongly disagree' to 'strongly agree') on the following items: "I really enjoyed participating in [program]" (M=3.75), and "my mentor gave me confidence in my ability to do well" (M=3.50).

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

These results are a positive indicator that participating in our program might lead to broader understanding of what STEM involves, making STEM a more accessible and attractive career path for girls. Furthermore, the results point to a direct improvement in girls' attitudes regarding their reported willingness to engage in employment in technology, or as a scientist or engineer.

KEYWORDS
Gender equity; School intervention; STEM careers.

Introduction

It is widely acknowledged that young children have positive attitudes to diverse forms of scientific enquiry in elementary school but that this interest declines when they transition to secondary school, and that 'by age 14, their attitude and interest in the study of science has been largely formed' (Archer et al., 2010, p. 617; Luttenberger, Steinlechner, Ertl, & Paechter, 2019). Research suggests that this decline occurs even earlier for girls, and that they tend to lose interest in Science, Technology, Engineering and Mathematics (STEM) 'around the age of 11, and the rate of interest loss increases as they progress through secondary education' (Sadler et al., 2012; Stoeger, Duan, Schirner, Greindl, & Ziegler, 2013, p. 410). As a consequence of this drop in interest, a range of initiatives designed to encourage young girls to engage more fully with STEM subjects have emerged, particularly in the past two decades (Gorbacheva, Craig, Beekhuyzen, & Coldwell-Neilson, 2014; Tsui, 2007). These initiatives take many shapes and often look to reverse the 'leaky pipeline' by addressing issues at the school and student level (van den Hurk, Meelissen, & van Langen, 2019). The pipeline metaphor is based on the idea of an 'ever-narrowing' trajectory towards STEM careers, with individuals lost at junctions along the pipeline, and very few emerging at the end to be retained in STEM careers (Cannady, Greenwald, & Harris, 2014, p. 444).

While the importance of initiatives to promote young girls' interest in STEM at these junctions has been well-recognised (Engineers Australia, 2022) and many such initiatives have been designed; studies focusing on the efficacy of these interventions often report on anecdotal evidence of increased interest in these subjects for girls (Prieto-Rodriguez et al, 2020). Intervention evaluations often do not use validated instruments, or do not account for participant self-selection into the studies, they rarely offer insights into the long-term effects of the programs, and more infrequently, include control groups to account for causal inferences (Archer, DeWitt, & Dillon, 2014). A recent systematic review investigating the effectiveness of STEM-related interventions found that only 9 of the 500 studies they evaluated had control groups and concluded that 'not many robust studies assessing the effects of interventions are available' (van den Hurk et al., 2019, p. 162). Another recent meta-analysis of literature, focusing exclusively on interventions designed for girls, found that only 5 interventions of the 32 reported in published studies, showed evidence of success in promoting long-term participation in STEM (Prieto-Rodriguez et al, 2020). Like in the case of the study by van den Hurk et al. (2019), this meta-analysis could thus not infer any causal relationship between the intervention and their reported success. However, it identified some factors that were common in interventions whose longitudinal evaluation reported sustained engagement in STEM by young women. Among those, the development of a STEM identity and the push to resist stereotypes appeared to be highly influential in engaging girls in STEM in the long term.

Loise Archer and her team have conducted substantial research into the development of science identity, and recognize that this identity development requires overcoming a range of stereotypes, as well as finding a way for young people to see themselves as scientists within the context of traditional school subjects (Archer et al., 2010). Indeed, success to encourage girls towards STEM appears correlated with girls coming to understand that science is 'a meaningful part of their lives' and that they can 'view themselves as active participants in the scientific endeavor' (Adams, Gupta, & Cotumaccio, 2014, p. 15). Similarly, being able to identify themselves as 'legitimate participants in STEM' has been heralded as an important factor in ensuring girls choose STEM subjects in high school and at university (Hughes, Nzekwe, & Molyneaux, 2013, p. 1980). In terms of outreach initiatives, it becomes clear that increasing engagement is not enough; a meaningful connection with STEM needs to develop for young people to continue their study of the subjects beyond their compulsory school years and into university and beyond.

The work of Carlone and Johnson is also considered seminal when defining what a STEM (or science) identity is for young women. They postulate of a female scientist:

[…] demonstrates meaningful knowledge and understanding of science content and is motivated to understand the world scientifically. She also has the requisite skills to perform for others her competence with scientific practices (e.g., uses of scientific tools, fluency with all forms of scientific talk and ways of acting, and interacting in various formal and informal scientific settings). Further, she recognizes herself, and gets recognized by others, as a ‘‘science person’’ (2007, p. 1190).

Enjoying science is thus not enough to ensure girls choose to study it as they progress through high school (Archer et al., 2010). If science is to take a position in students’ lives, it is essential that STEM ‘becomes’ a part of themselves (Kozoll & Osborne, 2004, p. 158) and that they are made aware of the range of career options where they, as not only as individuals but as females, can see themselves participating (Engineers Australia, 2022). The other factor identified in successful interventions according to Prieto-Rodriguez et al (2020), is those which provide tools to resist stereotypes. These types of interventions, aim to identify and challenge beliefs, biases and discriminatory practices which assume girls’ unsuitability or incapacity for STEM (Liben & Coyle, 2014). One way to achieve this goal is through mentoring. Dasgupta calls this type of intervention a ‘stereotype inoculation model’ (Dasgupta, 2011, p. 231). In this model women are exposed to ingroup members, women who could be considered ‘experts and peers in high-achievement settings’ who act as ‘social vaccines’ by increasing the feeling of belonging to help ‘inoculate fellow group members’ self-concept against stereotypes’ (231). Indeed, mentors have been shown to make a ‘tremendous difference’ to the way girls relate to STEM (McCreedy & Dierking, 2013, p. 8). Mentors, particularly when close in age to their mentees, are readily seen as intermediaries between the traditional roles of teacher and student, guiding participants without taking control. Providing female mentors might go some way to destabilising the stereotype of STEM as a masculine endeavour.

This paper reports on the process design and evaluation of an intervention aimed specifically to increase STEM participation in young females. The intervention, which took the form of a high school program for Year 8 and Year 10 girls (ages 13-16), was designed in consideration of the factors found in the literature described above. In particular, we aimed to help our participants develop a STEM identity via sustained engagement with a project supported by young female role models. In the section below we describe how the design of the program was informed by the literature on these two factors.

Program Design

Setting

The intervention program was delivered in nine co-education high schools (eight public and one Catholic school) in the Hunter region of New South Wales, Australia, in 2017, 2018 and 2019. The program runs for 10 weeks across the second term of the Australian school year. Seven of the nine participating schools had an Index of Community Socio-Educational Advantage (ICSEA) score below the national average of 1000 (Australian Curriculum Assessment and Reporting Authority [ACARA], 2020).

Participants and recruitment

The program was delivered to Year 10 girls (aged 15-16 years) in 2017 and to Year 8 girls (aged 13-14 years) in 2018 and 2019. The shift to targeting younger high school girls was made after receiving feedback that Year 10 girls had already made their subject choices about STEM, and it may be too late to impact these choices. Students were invited to participate in the study via different methods depending on which method/s each school deemed most appropriate and feasible. Recruitment was completed via providing invitations to: 1) all female students in the year group of interest; 2) female students who had already demonstrated an interest in STEM or had a high-level of academic achievement; and/or 3) female students who were in the participating teacher/s class.

The High School Program

While limited by funding constraints and the impact on girls’ school timetabling, the intention of this intervention was to design a program which ran over several weeks rather than just a day or two.

Research indicates that by taking part in long-term interventions (longer than two-weeks) participants ‘simultaneously learn science, do science, and develop a science affinity-identity’ (Adams et al., 2014, p. 15). Long-term programs are more likely to lead to an affinity with STEM, and engagement in STEM education ‘programmes focusing on knowledge, ability, motivation and feelings of belonging [often developed in long-term programmes] could increase the interest and persistence in STEM education’ (van den Hurk et al., 2019, p. 161). Long-term interventions affording contact with STEM professionals also appear to foster the development of a STEM identity which positively affects participants ‘ability to see themselves as the kind of people who could be legitimate participants in STEM through their interest, abilities, race, gender, and culture’ (Hughes et al., 2013, p. 1980). These interventions provide students the opportunity to develop relationships with mentors and peers, to feel part of a STEM community, and to develop a ‘sense of ownership’ over a project (Boudria, 2002, p. 719).

Weekly workshops with mentors

Throughout the 10-week program, the girls work in teams of three or four, with ongoing and sustained support from a mentor via weekly visits to the school or via video conference meetings in certain cases when a visit was not possible. The program was designed to offer female students the opportunity to explore STEM fields through meaningful project-based learning. During weekly workshops with mentors, girls were encouraged to choose local community issues that are significant to them, and decide on their own STEM-based solutions to that problem. Incorporating a hands-on or practical element into our program was a priority. The literature indicates that interventions’ emphasis ‘on creativity and innovation increased [participants] interest in engineering careers’ (Ivey & Palazolo, 2011, p. 8). Experiencing real-world contexts is also identified as important with success more likely when learners work with ‘expert mentors in authentic contexts over an extended period of time’ (Hughes et al., 2013, p. 1981). The structure of the weekly workshops is flexible to encourage the girls to lead the creation of their own STEM-based solutions with the support of mentors when needed.

The mentors are female university students studying in a broad variety of STEM areas. The intention of having female mentors was in the hope that they might act as role models for our participants, exemplifying what is possible for girls who stick with STEM studies. Providing female mentors might go some way to destabilising the stereotype of STEM as masculine. With this in mind we wanted to explore Dasgupta’s ‘stereotype inoculation model’ described in the introduction (Dasgupta, 2011). For the girls in our program to develop a STEM identity, we deliberately chose mentors to be much closer in age, so that they could relate to them, not only as STEM ‘people’ but also as individuals with a recent trajectory into STEM studies.

Industry or University Visit

Our program links each participating school with a sponsor that funds the intervention. Sponsors are from a range of local industries and faculties within our university. Halfway through the program, girls experience a visit to a site facilitated by their sponsor. Schools sponsored by the university, visit its main campus where they are exposed to research facilities, and spend an extended amount of time with their mentors and can get to know researchers. Those sponsored by industry visit a location such as a mine, a port, a lab, or a water recycling facility, where they observe STEM processes and meet STEM professionals, many of whom are women. The aim of the site visits is to show girls what type of careers are possible in STEM and what these careers look like in practice.

Final presentation

Approximately one month after completion of the program, a final presentation is held to showcase their STEM solutions. The girls present their solutions in the form of video pitches, showcasing their prototypes. During this event they receive feedback from a panel of local industry members in a ceremony that celebrates the contributions of the girls, their mentors, and female STEM professionals in our region. Family members are also invited to attend and celebrate.

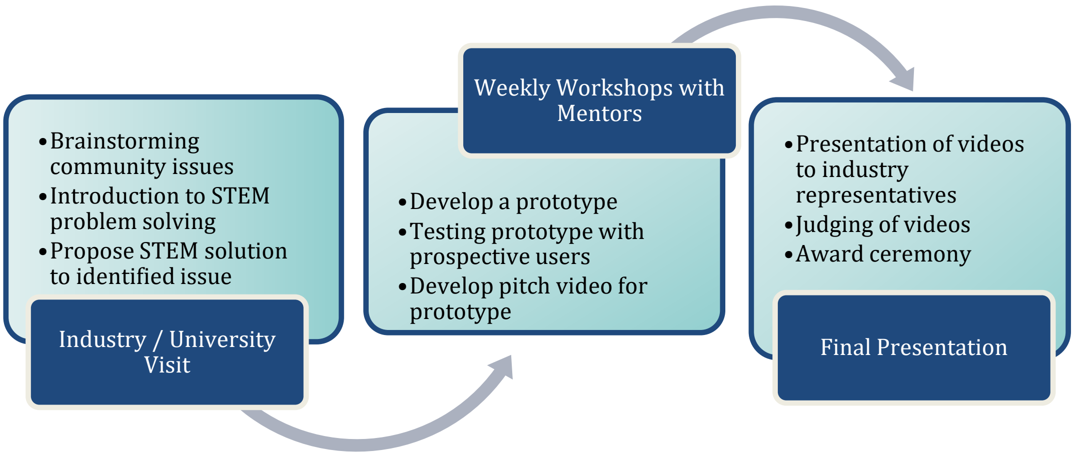

Figure 1: Schematic of outreach program

The structure of the program is loosely based on the Tech Girls are Superheroes competition (Gorbacheva et al., 2014), which is similarly modelled on the global Technovation program. We have borrowed some of their imagery in the resources we provide to the girls and adapted their final marking rubric for the projects. However, the program has some significant differences, including close linkage with local industries, a broader STEM focus, and the close relationships established with the mentors through small group interactions over a sustained period. It also presents a difference due to the small scale of the project and the significant input that teachers can provide to the evolution of the program.

The program is delivered at no cost to students or the school. Guiding activities are provided every week to aid progress with scoping and prototyping. These activities are mapped to three different State curriculum areas (Technology, Mathematics, and Science) to support teachers with the integration of the program activities within their school practice. Teachers participating in the program also receive ten hours of State-accredited professional development. A full schematic of the program can be found in Figure 1.

Sample and instruments

Girls participating in the program in 2017 (N=27), 2018 (N=69), and 2019 (N=104) were invited to complete two surveys immediately before and two weeks after the final presentation. Out of this total sample, we obtained 154 responses to the pre-intervention survey and 74 post-intervention. We had to cancel the program in 2020 due to COVID-19.

The aim of the evaluation was to explore whether the following measures were impacted by participating in the program: identity development, citizenship, interest, attitudes, future priorities, and motivations. The pre- and post- intervention surveys contain three scales from the ROSE survey which has been administered in 40 countries to assess factors impacting the attitudes and motivations of students regarding science and technology (Schreiner & Sjøberg, 2004; European Commission, 2021; Chang et al., 2009). The scales are “My science classes”, and “My opinions about Science, Engineering and Technology”. In 2019, we also included two scales about their relationship with their mentors and their experience of the program, with just over 50% of participants that year completing the post-intervention survey (N=57). The surveys were analysed using descriptive and inferential statistics. We also qualitatively analysed the final projects produced during the program using as evidence their video pitches (N=42). In these pitches the girls described their projects in detail and showed examples of their use, explaining both their community issue and their proposed STEM solution.

Results and Discussion

As mentioned above, we encourage girls to choose any community issue that they are interested in. The topics varied widely from pollution clean-up and prevention, energy saving, low exercise uptake among young people, wildlife protection, and metal health or bullying. The solutions to the community issues also range widely, from making solar charging stations for phones at the beach, to designing and building small educational recycling stations near parks. The themes of the community issues and the number of projects in each theme can be seen in Table 1 and an example of the work produced by the girls is presented in Figure 2.

Table 1. STEM solution types and community issues identified

Type	Community Issue	# of projects
App	Road safety	3
	Litter	3
	School life organiser	1
	Saving water	1
	Diversity in sport	1
	Mental Health	3
	Fitness	1
	Rural area activity finder	3
	Biodiversity	2
	Ride share	1
Website	Canteen payments	1
	Poverty, donations	2
	Farmer direct sales	2
	Adopt a pet	1
	Mental health	1
	Contamination awareness	3
	Weather warning App	1
	Safety in social media	1
	Sport items buy/sell	1
Physical prototype	Recycling sorter reward system	3
	Mining regeneration	1
	Recycling paper machine	1
	Mobile charger	1
	Contamination awareness	3
Augmented reality game	School orientation	1

Next, we analysed the items from the ROSE survey looking for changes from before to after the intervention for all years (2017-2019) combined. All items in the survey were presented to participants in a 4-point scale from Strongly Disagree (coded as 1) to Strongly Agree (coded as 4). We observed changes in participants' perceptions across time in 13 out of 20 items (see Table 1). An unpaired-samples t-test was conducted to compare students' perceptions prior to attending the intervention and after attending. We used an alpha level of .05 for all statistical tests, and using this criterion, we found three items showing significant improvement pre- to post- program with False Discovery Rate correction applied.

Our data indicates that girls had a significant improvement in attitude towards wanting to be a scientist or engineer ($t(122) = -3.42$, $p=.001$). This is a positive outcome, considering our initial intention was to promote interest in STEM careers. As well as this, we observed an overall improvement in attitude towards STEM careers, indicated by responses to a statement about whether science has opened the girls' eyes to new and exciting jobs ($t(140) = -3.01$, $p=.003$). This supports earlier research which suggests that STEM programs have enhanced 'awareness and understanding of science and introduced [participants] to a variety of science content and science-related careers' (McCreedy & Dierking, 2013, p. 19). Providing this awakening to the opportunities available and providing an understanding of what STEM careers might look like, is essential in increasing female participation.

Figure 2: Apps are favoured by girls as solutions to their community problems

Table 2: Items showing positive change after the program

		N	Mean	Std. Deviation	Std. Error Mean
Science has opened my eyes to new and exciting jobs*	pre-	150	2.60	0.843	0.069
	post-	70	2.96	0.806	0.096
I like science better than most other subjects	pre-	150	2.41	0.875	0.071
	post-	70	2.56	0.927	0.111
The things that I learn in science at school will be helpful in my everyday life*	pre-	150	2.77	0.761	0.062
	post-	71	3.07	0.762	0.090
Science has increased my curiosity about things	pre-	150	3.05	0.817	0.067
	post-	69	3.16	0.868	0.105
Science has shown me the importance of science for our way of living	pre-	150	3.11	0.743	0.061
	post-	70	3.19	0.767	0.092
I would like to become a scientist or an engineer*	pre-	149	2.08	0.941	0.077
	post-	71	2.59	1.077	0.128
I would like to have as much science as possible at school	pre-	150	2.53	0.946	0.077
	post-	37	2.61	0.951	0.156
I would like to get a job in technology	pre-	149	2.27	0.851	0.070
	post-	70	2.56	0.862	0.103
Science, engineering and technology make our lives healthier, easier and more comfortable	pre-	143	3.37	0.647	0.054
	post-	71	3.39	0.783	0.093
Science, engineering and technology can solve nearly all problems	pre-	143	2.67	0.767	0.064
	post-	70	2.83	0.932	0.111
Science, engineering and technology are helping the poor	pre-	136	2.54	0.868	0.074
	post-	70	2.71	0.903	0.108
Scientists and engineers follow the scientific method that always leads them to correct answers	pre-	142	2.39	0.816	0.068
	post-	71	2.68	1.053	0.125
We should always trust what scientists and engineers have to say	pre-	140	2.44	0.858	0.073
	post-	70	2.54	1.023	0.122

* Indicates a significant improvement pre- to post- program using an alpha of 0.05.

As well as making girls more aware of STEM career options, results suggest that our program has also lead them to perceive the ways that things they learn in science at school will help them in their everyday lives (t(219)=-2.71, p=.007). The ability to apply science to real-life situations has also been identified by others as important, if girls are to become, and to remain, engaged in STEM fields. Multiple research teams have taken this into account when designing STEM interventions for girls (Bogue, Shanahan, Marra, & Cady, 2013; Locklear, 2014). When science and engineering have a real-life context, or can be seen to make a difference or improve the world, they become more meaningful to girls, contributing to their identity as scientists (Demetry et al., 2009).

Table 3: Means and Standard Deviation for items in the survey relating to satisfaction with the program and mentors

	Mean	Std. Deviation
Program satisfaction		
I really enjoyed participating in [program]	3.75	0.44
I would recommend [program] to other girls in my school	3.54	0.51
I learned in [program] how STEM can be part of my life	3.39	0.73
I learned in [program] that STEM thinking is a way to raise questions and seek answers	3.53	0.56
I learned new things making my [program] project	3.53	0.61
Mentors		
My mentor game me confidence in my ability to do well	3.50	0.79
My mentor encouraged me to ask questions	3.63	0.67
My mentor listens to how I would like to do things	3.63	0.70
My mentor tries to understand how I see things before suggesting a new way to do things	3.67	0.74
The mentor is available for questions	3.81	0.52

In terms of experience with the program and mentors, the overall reception was very favourable as can be seen in Table 3. The influence of mentors, and a feeling of belonging appear to have had a strong influence on girls' positive attitudes and affinity towards STEM.

Conclusions

In 2016, our team developed a new program to increase female participation in STEM in our university's local region. We are a group of academics known for being strong advocates for female STEM participation, and some of us have a marked interest in STEM educational research. Our local region employs a significant proportion of the working population in STEM fields (approximately 38%), but, like everywhere else in the country, women remain grossly under-represented. This inequity could lead to a shortage of STEM workers, potentially placing limitations on economic outcomes (Commonwealth of Australia, 2019). This underrepresentation is also reflected in enrolments at our university. At the time our program was initiated, the Engineering student cohort was 12% female, the Science and IT cohort was 34% female, Electrical Engineering and Computer Science were both 9% female, and Information Technology was 13% female. These figures have remained steady for many years.

In this context we created an evidence-based intervention designed to increase female participation in STEM, taking into consideration a thorough literature review into what makes these interventions effective, and what steps can be taken to measure this effectiveness. We did so as we believed that too often 'well-intentioned individuals embark upon intervention programs without a clear understanding of what 'the problem' is for which the intervention is the solution', and that planning of interventions must focus first on a 'theorisation of 'the problem' rather than acting upon an intuitive sense of what is wrong' (Trauth, 2012, p. 53).

Our data indicates that our program has had a positive influence on girls' attitudes to STEM and STEM careers in several ways. The intention of our program is to spark girls' interest in STEM, with the long-term hope that they would enrol in tertiary STEM programs, and progress to a STEM career. While we have not seen improvement in attitude in all the areas, our data certainly reveals that participants have emerged from our program with a better understanding of the scientific method, a clearer picture of how science can be applied in the real world, and with a broader cognizance of the STEM careers available to them in the future. Most importantly, after participating in our program, girls show an improved attitude towards being a scientist or engineer. For us, this is a positive indication that our program has had an impact on the participant girls' attitudes towards STEM and has the potential to influence their decision to pursue a STEM career in the future.

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