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Re-Engineering the "Leaky Pipeline" Metaphor: Diversifying the Pool by Teaching STEM "by Stealth"

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ABSTRACT
Many attempts to engage diverse audiences in science, technology, engineering and mathematics (STEM) target students already enrolled or interested in STEM subjects. This paper presents qualitative findings on the characteristics and experiences of high school girls who participated in a STEM engagement programme involving drone-flying camps in two locations in regional northern Australia. As expected, the programme attracted students with a STEM interest, yet close to half of the participants named arts and humanities as their favourite subject areas. Our research suggests that engagement activities that primarily target students who already enjoy STEM will inhibit the capacity to attract diverse engineers. Programmes engaging with girls who do not identify as the "STEM type" may broaden engineering recruitment outcomes. Moreover, reimagining STEM beyond the boundaries of the traditional "hard sciences" works to overcome stereotyping that begins early in life (Bond, 2016; Kessels, 2015). We argue that the "pipeline" metaphor is part of the problem: it implies a singular pathway into engineering that is shaped by narrow curricular concepts of STEM education. Instead, we suggest that engineering disciplines should consider recruiting from a "deep pool"—one that recognises and values the dispositions generated through engagement with creative and critical curricula.

KEYWORDS
Gender equity; leaky pipeline; deep pool; STEM engagement; drone-flying camps

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INTRODUCTION

The engineering profession has known about its "diversity problem" for quite some time (i.e., Chubin, May, & Babco, 2005) and, along with other science, technology, engineering and mathematics (STEM) fields, has made efforts to diversify its workforce, placing particular emphasis on recruiting more women to the field. The problem of attracting and retaining women to STEM fields broadly, and engineering fields specifically, is often conceptualised as a "leaky pipeline," in which any increased recruitment of diverse students and staff is offset by attrition at various stages of education and employment (Watson & Froyd, 2007). Despite some suggestions of different metaphors (Watson & Froyd, 2007), the pipeline metaphor remains a popular way to conceptualise the lack of diversity in STEM fields. "Stopping the leaks" from engineering is considered important, not only for reasons of social justice, but also because the field itself has recognised that a diverse workforce brings with it diverse perspectives that improve the quality of group problem-solving and approaches to innovation (Gibbs, 2014; Watson & Froyd, 2007).

This paper presents the findings of qualitative research on girls aged 10–17 who participated in a STEM engagement programme involving drone-flying camps in two locations in northern Australia. Our research suggests that engagement activities that are limited to targeting students who already enjoy STEM, or who already enjoy academic success in the traditional disciplines of science and/or mathematics, may inhibit the capacity to attract young women who are generally curious, who like to learn by doing, and who are interested in thinking creatively to solve problems. Reimagining "STEM" beyond the boundaries of the traditional "hard sciences" works to further overcome stereotyping that happens very early in schooling (Bond, 2016), whereby girls are less likely to enjoy STEM subjects because of the cultural contexts that tell them girls do not *do* STEM (Kessels, 2015). In contrast, engagement activities that operationalise a "STEM with attitude" (Timms, Moyle, Weldon, & Mitchell, 2018, p. 2) framework may work to diversify engineering recruits, as they foreground 21st-century skills as integral to the work of a contemporary STEM professional. Such a framework provides a context within which young women can imagine possibilities and opportunities that could arise from engaging with these aspects of their STEM identity.

In reimagining the operationalised boundaries of STEM, we argue that the pipeline metaphor is itself part of the problem, as it implies a singular pathway into engineering. To extend the metaphor, pipes have a fixed diameter, implying that the characteristics required to enter the pipeline are both fixed and rigid. Instead, we argue that the field of engineering should look to engage young people from a larger pool of capabilities and dispositions, and then provide opportunities through which young women in particular "can explore their potential, curiosity and passion for innovation" (Bontempo, 2017, para. 2).

CONTEXT

This research focuses on one particular STEM-engagement programme, namely, drone-flying camps for girls in northern Australia. Organised by the start-up *She Flies*[1] and funded by an Australian Government Women in Science and Engineering (WISE) grant, camps were held in three locations: Cairns, Queensland; Darwin, Northern Territory; and Karratha, Western Australia. The camps were designed in response to the massive underrepresentation of women and girls in drone careers. The programme provided girls with an opportunity to try flying and coding mini drones, and to meet and engage with peers and role models (for more on the programme design, see Howard, Morgan, Doyle, Harrison, & Petray, in review). The *She Flies* camps aim to deliver a technology-based programme, albeit one with specific social and political goals. Promotion for the camps was centred around the opportunity for girls to fly drones in a girls-only space, and highlighted problem-solving, creativity, and innovation as central aspects. The *She Flies* website included the slogan "She Flies because she can" and featured images of school girls, wearing casual clothes, flying drones. The website also shared the personal story of one of the founders, Dr Karen Joyce, and featured her seven-year-old son as a "chief drone tester." The website emphasised a sense of fun and normalised the concept of girls flying drones. Rather than targeting high-achieving STEM students through school-based recruitment, the Cairns and Darwin camps were publicised via social media, STEM mailing lists, and word of mouth within existing local networks. Participants were selected on a first-come, first-served basis from expressions of interest sent in response to this publicity campaign.

The *She Flies* programme team attended each camp location for one week, holding two separate three-day camps per location with the third day attended by all participants. The present study centres around two of the *She Flies* camps—those in the regional northern Australian cities of Cairns and Darwin in July 2017, as last minute changes to delivery of the Karratha camp meant there was insufficient time to put in place the ethics approvals required for that site. Cairns, with an estimated local population of 164,536 people (idCommunity, 2018a), is located in Far North Queensland, approximately 1700 kilometres (1056 miles) north of Queensland's capital city, Brisbane. Darwin, Australia's most northerly city and capital of the Northern Territory, lies approximately 2800 kilometres north-north-east of Cairns and is home to an estimated 84,364 local residents (idCommunity, 2018b). Darwin and Cairns have some of the highest Indigenous populations of any Australian city, with 8.7% and 10% of the respective local residents identifying as Australian Aboriginal and/or Torres Strait Islander people, as opposed to a national rate of 2.8% (Australian Bureau of Statistics, 2016).

For decades, a plethora of attempts to engage underrepresented young people in STEM have occurred, and continue to occur, in developed OECD countries. Through both formal and informal learning opportunities, these initiatives have sought to prepare young people with the requisite skills and knowledge of an innovation-led economy. These "STEM learning opportunities" may occur in a range of settings, including schools, museums, and throughout communities (DeWitt & Archer, 2017).

[1] The start-up has since changed its name to *She Maps*.

Together, these diverse settings comprise a "STEM learning ecosystem" (Falk et al., 2012; Russell, Knutson, & Crowley, 2013; Traphagen & Traill, 2014). STEM learning experiences span a continuum from formal STEM subjects delivered by teachers in classrooms and tightly aligned with government curriculum imperatives, through to extracurricular "STEM learning opportunities" offered in other parts of the STEM learning ecosystem. Therefore, it is important to interrogate the way in which formal school curriculum structures may intersect with, or even undermine, attempts to recruit women and underrepresented people in extracurricular STEM activities who may not self-identify as "the STEM type."

In this paper, we focus on STEM education in general, as few countries offer a distinct engineering curriculum in secondary schools. A critical view of formal school curriculum structures acknowledges that such curricula are not neutral (Teese, 2007, p. 58) and recognises the curriculum's role in constructing knowledge hierarchies, sorting and streaming individuals, and valuing particular fields of knowledge over others—with STEM subjects at the top of the hierarchy. Further, each subject has its own reputation, uses, and "strategic and functional applications beyond the purely formal objectives of the syllabus design" (Teese, 2007, p. 45). Conceptions of STEM as science may work to limit the views that people hold about what it means to be someone who *is* engaged with STEM, or—more to the point—is considered by others (teachers, parents, community members) to be *able*, or perhaps *permitted*, to be engaged with STEM. Moreover, these perceptions shape one's own STEM identity, which is defined by Carlone and Johnson (2007) as a way in which individuals make "meaning of science experiences and how society structures possible meanings" (p. 1187). Programmes with the best of intentions do not always achieve their desired outcomes if they are not placed within the social contexts that influence STEM identity development (Howard et al., in review).

At the same time that the *She Flies* camps were taking place, Queensland senior science and mathematics curricula were being designed by the responsible jurisdiction—the Queensland Curriculum and Assessment Authority (QCAA). These new curricula are being delivered for the first time to Year 11 students (16 years of age) in Queensland secondary schools, beginning in the 2019 school year. The traditional science and mathematics disciplines represented in the QCAA curricula are underpinned by a rationale that foregrounds 21st-century skills, including critical and creative thinking, communication, collaboration and teamwork, personal and social skills, and information and communication technology skills (QCAA, 2018). However, the modes of assessment outlined in the curriculum, particularly in the disciplines of science and mathematics, privilege the mastery of discipline-specific domain knowledge and skills as evidenced by the introduction of a high-stakes (50% of course grade) external examination to be completed at the end of Year 12. Assessment drives practice, and the modes of assessment drive the ways in which curricula are enacted. These changes, both to the curriculum and its assessment, create a tension for schools and teachers. Whilst "STEM with attitude" approaches—those focused on the development of personal skills and attributes such as problem-solving skills, creativity, innovation, and collaboration (Timms et al., 2018)—might be practiced in some discipline-specific lessons (for example, conducting a hands-on experiment in a classroom as part of a group), teachers

must find time and enact strategies that prepare students for "cognitive mastery" (QCAA, 2018) so that they can successfully, and individually, respond to written examinations. Changing national or state-level assessment practices to better prioritise 21st-century skills may be difficult to achieve. Extracurricular programmes such as the *She Flies* drone camps can, therefore, fill some important gaps.

LITERATURE REVIEW

Engaging Women and Girls with STEM in Australia

Both the Australian central government and many state governments have made public commitments to improving women and girls' participation in STEM. The "problem" of participation is often attributed to "leaking pipelines" and therefore solutions need only plug the leaks through better recruitment or engagement practices; fixing women and girls' deficient STEM skills; and providing incentives to participate in the STEM ecosystem. For example, at the national level, the Australian Government's National Innovation and Science Agenda (NISA) aims to increase women's participation in the STEM "innovation ecosystem" by fostering interest, developing innovation and entrepreneurial skills, and building professional networks—also via the Women in STEM and Entrepreneurship (WISE) programme (Department of Industry, Innovation and Science [DIIS], 2016). A *Women in STEM 10-Year Road Map* is being developed by the Australian Academy of Science and the Australian Academy of Technology and Engineering to inform the national strategy to support women and girls in STEM (Australian Academy of Science, 2018; DIIS, 2018). At the state level, the Queensland Government, under the Advance Queensland suite of programmes, aims to increase participation through prizes, women's funds, and girl power camps. In addition, extracurricular engagement programmes are increasingly common and aim to raise students' aspirations towards STEM careers (Sadler, Eilam, Bigger, & Barry, 2016).

Yet, the level of research and evaluation of effectiveness and impact of these programmes is limited, especially when narrowed to the participation of girls in STEM (Sadler et al., 2016). Furthermore, for girls of Aboriginal and/or Torres Strait Islander heritage, the intersection of culture, race, and gender and their influences on participation in STEM require further investigation, indicating the importance of the influence of structural factors on STEM participation (see Crenshaw, 1994; Paige, Hattam, Rigney, Osborne, & Morrison, 2016). Aboriginal and/or Torres Strait Islander student participation and completion of STEM subjects or courses in high school and higher education remain significantly lower than non-Indigenous student participation rates (Paige et al., 2016). In part, this has been attributed to the "potential mismatches between the epistemological, ontological and cosmological contexts of Indigenous Knowledges and institutionally located Western STEM cultures and worldviews . . . , including the philosophical foundations of notions of aspiration and success" (Paige et al., 2016, p. 3). Government responses to declining STEM participation that focus on recruitment and retention of students therefore miss addressing fundamental factors that influence STEM identity development, STEM capital, and the structural factors that lead to continued stereotypes of STEM as white, middle-class, and male (Hughes, Nzweke, & Molyneaux, 2013). Factors influencing the participation of girls in particular, include: perceived self-efficacy; willingness to operate outside of "traditional"

female roles; access to role models (van Aalderen-Smeets & van der Molen, 2018; Aidis & Weeks, 2016); perceived irrelevance of STEM curricula to girls; teacher bias towards STEM as primarily the domain of boys; and perceptions that engagement in STEM requires greater intelligence and is more suited to males (Holmes, Gore, Smith, & Lloyd, 2017). Studies have also highlighted that girls may feel less capable than boys despite their equal or greater ability in STEM areas (Holmes et al., 2017) and this impacts on their motivational beliefs and resilience (van Aalderen-Smeets & van der Molen, 2018). Importantly, high performance in STEM is not considered likely to influence future career choices for girls, whilst the converse is true for boys (van Aalderen-Smeets & van der Molen, 2018).

Stereotypes and expectations around feminine and masculine roles have been found to influence girls' early choices and aspirations towards activities, studies, or careers that are regarded as fulfilling a "normal" female role (van Aalderen-Smeets & van der Molen, 2018; Aidis & Weeks, 2016). STEM fields tend to be regarded as "things-and-male-oriented" with the potential to impact negatively on "feminine" lifestyles or family-work balance (Cheryan, Master, & Meltzoff, 2015; van Tujil & van der Molen, 2015, p. 174). These stereotypes can influence the development of a STEM identity, or the "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). Furthermore, the secondary school curriculum itself presents a structural barrier by ascribing greater value to knowledge domains and perpetuating hierarchical relationships that exist between hard (science/mathematics) and soft (arts/humanities) subjects (Teese, 2007). These hierarchies maintain gender stereotypes and sanction, or deny, the opportunity to blend "soft" skills such as creativity, innovation, and artistic ability with "hard" knowledge in STEM.

In a recent report on best practice in promoting women and girls' participation in STEM, Chapman and Vivian (2017) highlight a lack of research dedicated to understanding the barriers and motivators to girls' participation in STEM specific to the Australian context. Chapman and Vivian have identified key stakeholder groups that influence the participation of girls in STEM. These groups include family, cultural groups, peers, clubs, schools, and the STEM industries (Chapman & Vivian, 2017). In addition, we argue for the importance of a *structural* layer that can explain inhibitors or enablers of participation, which is shaped by geographic location, and social, economic, historical, and cultural contexts (Howard et al., in review). Consideration of this structural layer is important, given that *She Flies* drone camps in northern Australia engaged with students who share demographics with the groups who are less likely to engage in STEM education—that is, "girls, students from low socio-economic backgrounds, Aboriginal and Torres Strait Islander students, and students from non-metropolitan areas" (Chapman & Vivian, 2017, p. 13).

The challenge for those who seek to ensure diversity within engineering is to consider the ways in which success is defined and evaluated; to challenge stereotypical constructions of the STEM type; and to focus on diversifying recruitment processes by recognising alternative ways of working. This means a

focus on the systems and structures—including stereotypes and gendered workplaces—that influence STEM access, aspiration, and participation rather than simply representing the problem (Bacchi, 2009) as one of individuals "leaking from a pipeline."

METHODOLOGY

Our research was designed to evaluate the *She Flies* camps from both a critical (Althusser, 1971; Bourdieu, 1990; Freire, 1970/2000) and feminist (Baker, 2008, 2010; Fraser, 1989; Gillies, 2005; Smith, 1999) perspective.

Our primary sources of data were pre- and post-camp questionnaires, designed to capture the experiences of the girls who had participated in a *She Flies* camp. Not all girls who attended the camp had permission from their parents to engage in the research project; those responses were removed before analysis, giving us response rates ranging from 37.5% to 75%. Table 1 summarises the number of responses analysed for both the Cairns and Darwin camp locations.

Location	Dates	Number of camp participants	Number of valid responses – pre-survey	Number of valid responses – post-survey	Number of individuals who completed *both* pre- and post-survey
Cairns	June 26, 27 & 30, 2017	24	9 37.5%	13 54.2%	5 20.8%
	June 28, 29 & 30, 2017	24	15 62.5%	17 70.8%	13 54.2%
Darwin	July 10, 11 & 14, 2017	24	15 62.5%	12 50.0%	9 37.5%
	July 12, 13 & 14, 2017	24	18 75.0%	17 70.8%	17 70.8%
Total:		96	57 59.4%	59 61.5%	44 45.8%

Table 1. Camp locations, dates, and questionnaire responses. Valid responses are from those girls who completed the questionnaire and had parental permission to participate.

The questionnaire items were developed around four analytical themes, informed by the literature review presented above: equity and access; perceptions of STEM, mediated by school curriculum; development and transformation of girls' STEM identity; and protective factors for STEM participation (following Hughes et al., 2013; Sutherland, 2005). Questionnaire responses were analysed using a combination of descriptive statistics, correlations, and qualitative coding. Our qualitative analysis is informed by grounded theory (Strauss & Corbin, 1990), allowing themes to emerge that embrace diversity in experience, engagement, and worldview in addition to the four themes above. All quotes below are included as written by the participants and have not been edited.

The pre-camp questionnaire contained 22 items, and the post-camp questionnaire contained 19 items. Both were piloted with young people before being used in the research in order to assess the relevance of questions and terminology. An Indigenous advisor acted as a critical friend in the development of the questions in order to ensure cultural fit. Camp participants and their parents were informed of the research via email, with several completing the pre-camp questionnaire before arrival, although most completed the pre-camp questionnaire on arrival at the camp using mobile devices. The post-camp questionnaire was completed on the final day of the camp. Using a unique identifying code for each girl, we then removed all responses from girls whose parents/guardians did not sign consent forms for their participation in the research. We treat the data as descriptive and qualitative only, and do not make any claims of generalisability.

RESULTS

The questionnaire responses provide a demographic profile of the camps and point out some key differences between the two locations (Table 2). The camps in Darwin had a higher rate of Aboriginal and/or Torres Strait Islander respondents (21.2%; compared to 8.3% in Cairns). Darwin also had a higher rate of respondents from public schools, although public school students were the majority in both locations. Given the small sample sizes and the relatively minor differences between them, data are generally treated as a single cohort in the discussion.

	Cairns camps	Darwin camps
Sample Size	24	33
Age: range	10–15	10–16
Age: mean	12.1	12.4
Age: mode	12	11
Identify with Aboriginal cultural background	2	5
Identify with Torres Strait Islander cultural background	0	2
Public school	54.2%	63.6%
Private school	45.8%	36.4%

Table 2. Demographic information from questionnaire respondents in each location.
In the pre-survey, girls were asked to identify their favourite subject at school. This was an open-ended question and some girls identified more than one subject. Table 3 shows responses coded to broad STEM/HASS (Humanities, Arts, Social Sciences) categorisation, with responses counted in both categories if girls named a subject from each.

	Cairns Camps		**Darwin Camps**		**Combined**	
	Total	**%**	**Total**	**%**	**Total**	**%**
STEM ●Science ●Mathematics ●Digital Technology	15	62.5%	18	54.5%	33	57.9%
HASS ●Art ●Design/graphics ●Creative media ●Languages ●Drama ●History ●Humanities ●English	13	54.2%	13	39.4%	26	45.6%
Sport/HPE	0	0%	3	9.1%	3	5.3%
All subjects equally	1	4.2%	1	3.0%	2	3.5%

Table 3. Q: What is your favourite subject at school? (More than one answer could apply; open-ended responses are listed below the main category.)

Responses to this question were fairly consistent across both locations. Many girls explained their preferences in terms of 21st-century skills, such as creativity and problem-solving:

> ART or Technology because in art you can just explore and be creative, in technology you can do experiments, play around with stuff and find out how things work and if it fails just work out why and try again. (Cairns pre-survey participant)
>
> Art. I like being creative. (Darwin pre-survey participant)
>
> math and science, science allows me to be creative and math allows me to be exact. (Cairns pre-survey participant)

Five girls responded that their favourite subjects are those that challenge them, but another four favour those subjects they are "really good," "good," or "okay" at.

Girls were then asked about things that encourage or discourage them in their STEM studies at school. For most girls who identified STEM as their favourite study area, they reported feeling encouraged, whether by parents and teachers, or by their own success:

> No nothing will stop me from having them as my subjects next year and receiving good marks this year not even my friends. (Cairns pre-survey participant)

However, amongst those girls who prefer HASS subjects, feelings of embarrassment, stress, and frustration with STEM subjects, and especially mathematics, were commonly mentioned.

> Depression, stressed that I can't keep up or embarrass myself cause I might mess up and my friends aren't interested in some of these field so I don't want to do it alone. I'm afraid that I might not understand and might get left behind. (Darwin pre-survey participant)
>
> I don't really like maths, and i find it very difficult and frustrating sometimes. I really like technology and I find it fun, but sometimes I get very frustrated when I try things all the ways I can think of, but it still wouldn't work. Science is okay, but sometimes it gets frustrating because you can't seem to remember the right answer for the question. (Cairns pre-survey participant)

The other common frustration was a lack of subject availability, inability to participate in extracurricular STEM activities because of competing demands, or lack of hands-on experience in STEM classrooms.

Despite half of our participants indicating STEM subjects as their favourites, their reasons for attending the camp varied (Table 4). Responses were coded into three main themes: girls who specifically identified STEM, or a subject area within STEM,

as their key area of interest; girls who expressed an enthusiasm about learning new things in general; and girls who communicated excitement about drone-flying specifically. Overlaying these three themes was the importance of networking. Several girls noted the importance of meeting new people and making new friends, or seeing existing friends outside of school.

	Cairns Camps		**Darwin Camps**		**Combined**	
	Total	**%**	**Total**	**%**	**Total**	**%**
Interest in STEM broadly; to expand on STEM education	6	25%	4	12.9%	10	18.2%
	"I have decided to attend a she flies camp because I take an interest in stem and programming"		"Because I like doing things with technology and mathematics."			
Interest in learning new things generally	8	33.3%	12	38.7%	20	36.4%
	"because I would like to learn about more things and this is a great opportunity"		"Because I think it is a great opportunity to enhance my skills and learn new ones"			
Interest in drones specifically	10	41.7%	15	48.4%	25	45.5%
	"Because it is a great opportunity and I am really interested in the concept of being able to fly a drone"		"Cause drones"			

Table 4. Q: Why have you decided to attend a She Flies Camp? (Sample open-ended responses are listed below each category.)

In the post-camp surveys, we asked the girls to tell us the three most interesting things they learned from the camps. The overwhelming majority of responses, unsurprisingly, note practical skills: programming and flying drones, or the possible uses for drones. 87.7% of girls reported they had never flown a drone before attending the camp (although some of these girls made up the 22.8% of girls whose school has a drone), and they were clearly a drawcard for participants. Some, however, noted the problem-solving skills they developed, or the arts activities they also did throughout the camp. Two girls specifically commented on learning about the underrepresentation of women in STEM, with one of these girls commenting on the potential of the *She Flies* camps to improve this situation. Several girls noted that the camps have made them determined to study more STEM subjects in the future and pursue careers in STEM and/or flying drones. Some were quite specific about their plans, noting how drones may help them in photography or being a park ranger, but many made more general comments such as:

> Yes, I am planning to fly drones more and do more programming. (Darwin post-camp respondent)

Interestingly, even though many girls indicated their intention to study more STEM subjects after participating in the camps, they did not necessarily feel more encouraged to do so, despite their immersion in a STEM-positive environment, exposure to role models, and their success at problem-solving and creative thinking throughout the camps. Table 5 shows how many girls agreed that their family and teachers encourage their participation in STEM subjects. Table 6 shows that despite fewer girls agreeing that they are encouraged, more girls can envision a future career in STEM following the camps. Our focus in this analysis is on the girls as a cohort, rather than individual change between pre- and post-camp questionnaires. Given that 44 of 72 respondents (61.1%) completed both surveys, this indicates a substantial shift in attitudes over the course of the camp.

		Pre-camp	Post-camp	Change
Cairns	Family	100.0%	86.7%	-13.3%
	Teachers	91.7%	80.0%	-11.7%
Darwin	Family	84.8%	86.2%	+1.4%
	Teachers	84.8%	79.3%	-5.5%

Table 5. Q: Do you agree or disagree with the following statements? My [family/teachers] encourage me to participate in maths, technology and/or science subjects. The table shows the percentage of respondents who agree (other options were neither/unsure; disagree). Note that the post-camp survey had a larger sample than the pre-camp survey.

		Pre-camp	Post-camp	Change
Cairns	Agree	62.5%	80%	+17.5%
	Neither/Unsure	37.5%	20%	-17.5%
	Disagree	0%	0%	--
Darwin	Agree	45.5%	58.6%	+13.1%
	Neither/Unsure	45.5%	34.4%	-11.1%
	Disagree	9.0%	7.0%	-2%

Table 6. Q: Do you agree or disagree with the following statement? In the future, I could have a job in science, IT, design, or technology. Note that the post-camp survey had a larger sample than the pre-camp survey.

DISCUSSION

Our research highlights three important findings relevant to the design of STEM engagement activities aimed at recruiting a more diverse cohort of students to engineering and other STEM fields. First, nearly half of the girls (46%) named HASS subjects as their favourite subjects at school. Many of these girls were more likely to recognise feeling discouraged when they study STEM subjects, for reasons including fear of failure and a general lack of opportunities in subject choice or extracurricular activities. Second, a third of the girls (36%) chose to attend the camp because they like to learn new things in general, rather than because they wanted to learn more about STEM. Girls were interested in drones as cool toys, but they were also interested in problem-solving, creative thinking, and network building. Third, in both camps, girls felt *less* encouraged to study STEM subjects by their parents and teachers after they had spent three days at the *She Flies* camp. These three key findings will be the focus of our discussion.

In Australia, the curriculum intent is underpinned by the ideals of the 21st-century learner. However, enactment of the curriculum is largely driven by assessment. When assessment is tight and narrow, and defined by mastery of a given discipline, these 21st-century curriculum ideals are squeezed out of a curriculum that privileges knowledge over innovative, creative, and multi-disciplinary skills. This may result in narrow student perceptions of the work undertaken by contemporary STEM professionals (including engineers), what constitutes STEM talent, or indeed who might constitute the "STEM type." Often this is reinforced by STEM

engagement programmes aimed at "talent development" that limit selection or participation to students excelling academically in science and/or mathematics. Otherwise well-intentioned programmes risk excluding girls and students from underrepresented backgrounds. Engagement strategies targeting "STEM types" may inadvertently exclude an entire cohort of students who think creatively and enjoy problem-solving, and are thus potentially good engineers, yet who do not necessarily identify themselves as the "STEM type." Instead, the development, marketing, and recruitment for STEM engagement programmes need to emphasise 21st-century skills if they are to recruit more girls, more underrepresented girls, and more girls with STEM skills. In addition, programmes should move away from funnelling people into STEM programmes based on achievement in mathematics and/or science, and instead privilege capacities for communication, teamwork, creativity, and curiosity. Moreover, girls and young women need the opportunity to self-select, with these 21st-century skills clearly articulated as the criteria that they should consider when deciding to participate. For example, rather than targeting students who had already established success in STEM subjects, the *She Flies* programme was broadly advertised. It attracted both students who love STEM (57.9% of participants' favourite subjects were in a STEM area) and students with a broader love of learning, and the programme was thus able to challenge the stereotypical notion of the "STEM type" in the process. For some girls, this may have been enough to shift their self-understanding that they are "not a STEM type" before it solidifies. The relatively high participation rates of Aboriginal and Torres Strait Islander girls at the Darwin camps (21%) is also encouraging, given that many of these girls will need to circumvent cultural, racial, *and* gender stereotyping in order to participate in STEM domains.

Imagination is a central tenet to this discussion. Girls must be able to imagine themselves as STEM types when deciding whether or not to participate in STEM engagement programmes. However, the onus for this should not be placed on individual girls. Parents, teachers, extracurricular programme designers, engineering programme recruiters, and society more broadly need to clearly articulate the 21st-century characteristics of the STEM type, such that girls can reflect on these characteristics and attributes as they learn more about themselves and their capacities. The *She Flies* promotions for the camps focused on problem-solving, creativity, and innovation, which are key 21st-century skills. Programmes like the *She Flies* camps can provide girls with insights that the formal, assessment-focused curriculum cannot, because in such enrichment programmes, they can practice those skills needed to be a successful 21st-century engineer.

However, as was found through the survey results, the result of this increased clarity is that some girls returned to their school settings feeling less encouraged to study STEM. As girls were more likely to agree that they might possibly work in a STEM career in the future *after* attending the camp, we are not suggesting that girls are less inclined to study STEM. We also note that after spending three days in a highly supportive environment, it is possible that girls felt less supported by their teachers and families, relative to the *She Flies* camp staff. We argue that this sense may arise from the girls developing a more critical awareness of the disconnect between the formal school STEM curriculum and the 21st-century skills that they

now know are integral to STEM careers. Thus, paradoxically, a programme that was designed to empower girls and increase their awareness of the possibilities open to them may have also made them more aware of the barriers they face to participating in STEM. Yet increased awareness of a lack of support is not necessarily a negative outcome; indeed, it may serve to enable girls to act collectively towards changing those factors that sit outside of their direct control, rather than internalising any failures as a personal lack of ability to take advantage of assumed opportunities as 21st-century learners.

Moreover, programmes such as *She Flies,* which conceptualise STEM as a multi-disciplinary set of practices, allow disciplinary barriers to be broken down and, instead, reach a broader pool of potential engineers. This view of "STEM as a way of working" challenges stereotypical views that engineers are socially isolated, natural geniuses, and interested more in machines than in people (Cheryan et al., 2015). Adams and Felder (2008) identify independence, adaptability, understanding impact and different perspectives, and innovation as key outcomes for engineering curricula in the 21st century. Social learning—interacting with a diverse range of classmates, including from other STEM disciplines and from HASS areas—is one important strategy via which engineering educators could achieve these outcomes (Adams & Felder, 2008). Our participants have indicated that, regardless of whether they embraced STEM or felt discouraged by it, they appreciated the opportunity to explore and develop these skills in the *She Flies* camps.

Whilst the geographical location of northern Australia where participants in *She Flies* camps live provides an important context in terms of isolation to opportunity and resources, their desire to participate in STEM will also be influenced by personal factors such as life experiences and home environments, as well as broader structural factors such as stereotypes and access to opportunities. Gender is commonly referred to as something that is actively done, rather than innate or given (West & Zimmerman, 1987). Very early in their lives girls and boys learn how they should act, what interests they should have, and how to fit in with their social groups. Within this system, individuals are judged by others based on how well they fit within, or deviate from, gendered social expectations. Educational and occupational choices are just one of the many ways in which girls and boys are gendered throughout their lives (van Aalderen-Smeets & van der Molen, 2018; Aidis & Weeks, 2016; van Tujil & van der Molen, 2015, p. 174; Whitehead, 1996).

Thus, conceptualising a pipeline, whilst useful to identify leaks, is a limiting metaphor. It suggests a singular career pathway and thus makes it difficult for engineering to truly diversify, as it relies on individuals being funnelled (by schools, and by society more broadly) into the correct pipeline, and also on their ability to shape themselves to fit within that pipeline. No amount of family-friendly policies or inclusive outreach programmes (as vital as they are) will overcome the gendered sorting that begins even before school. Such initiatives will not help those who feel like they do not have access to the pipeline in the first place—especially women, Aboriginal and Torres Strait Islander people, and other underrepresented groups. Instead, the metaphor of a "deep pool" is more inclusive and less restrictive of who may enter engineering.

The research outlined here, with its focus on the *She Flies* camps, helps policy makers and educators to frame STEM engagement programmes in ways that do not present a "taken-for-granted" representation of STEM, whilst also drawing attention to the ways in which social structures and curricula work to reproduce inequities. The goals of STEM engagement programmes should be expanded to highlight opportunities to explore the individual's potential and propensity for engaging with, and enhancing, 21st-century skills and strengthening networks—as opposed to their primary purpose being simply to refine or deepen domain-specific knowledge, as defined by traditional disciplines of science and mathematics. Thus, the curriculum that was designed by *She Flies* provided opportunities for girls to increase their awareness of their own strengths and skills, and the possibilities open to them, should they wish to enact those skills. These experiences may have actually made the girls more aware of the ways in which they could imagine themselves participating in the STEM economy as 21st-century learners.

CONCLUSION

Any metaphor that narrows the pool of potential engineers before they even reach the discipline is inadequate. Not only is a pipeline always prone to leaks; if it is too narrow, it cannot accommodate all of those who should be considered potential engineers. Our research included girls who do not feel an affinity for STEM—indeed some expressed dislike, or felt frustration towards the field. It is currently impossible to separate individual preferences from social pressures, such as gendered career expectations. Thus, the best diversity inclusive programmes will not label themselves as engineering or STEM programmes, but rather appeal to participants who demonstrate (or are interested to develop) those characteristics identified by Adams and Felder (2008): independence, adaptability, understanding impact and different perspectives, and innovation. If such programmes then dispel stereotypes that suggest engineering is only suitable for a particular set of people (Cheryan et al., 2015), girls and other underrepresented minorities may be more likely to consider engineering as a possible pathway. By excelling in such programmes, and seeing diverse role models when they participate, girls and other underrepresented minorities may not only come to see themselves as capable, but also come to view engineering less as a male-oriented discipline.

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