Engaging the disengaged: A literature driven, retrospective reflection, of a successful student centric STEM intervention.

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CONTEXT

By the time students reach university the die is already cast, many will not choose engineering or related STEM disciplines because of poor experiences in their early education. Research suggests decisions about STEM careers are made in late primary school, where early education and environmental factors have tended to favour or filter individuals into very narrow demographics.

PURPOSE OR GOAL

This paper examines the literature around the early STEM engagement at primary and secondary levels, to see if students are more likely to choose engineering and related disciplines at tertiary level, because of early positive experiences. Them it was retrospectively applied to a successful pilot STEM intervention to identify factors of success.

APPROACH

The researchers used a snowball literature review to examine the problem of low STEM uptake and then applied it reflectively examine a pilot STEM intervention that was aimed at disadvantaged and disengaged students.

OUTCOMES

We used a literature driven methodological approach to assess a STEM intervention, as an aid to further developing a novel STEM intervention based on using physical activity and sport to harness intrinsic student interests in physical pursuits as a vehicle for teaching STEM and its relevance for future career choices.

SUMMARY

This investigation examined key confounding factors in STEM engagement related to gender, socio economic disadvantage and lack of appropriate or intellectual challenge throughout the literature. A methodology was developed from the literature to help assess engagement and was applied reflectively to a successful STEM pilot engagement intervention, that utilised sport as a vehicle. Future work is directed towards STEM intervention with a more complete range of measures using the developed methodology to assess the intervention more completely.

KEYWORDS

STEM, indigenous education, disengagement, gender

1. Introduction

Technological and computational advances are occurring at such a fast pace, that how jobs will look in the future is unknown. It is predicted however, that 75% of all jobs will require skills that are acquired through the study of STEM. This point has driven governments to highlight the importance of STEM learning. In the age of the internet, STEM transferable skills, such as critical thinking, are necessary to discern quality information from opinion and STEM is prioritised as an agenda to be implemented in school curriculums. Encouraging students to embrace STEM sounds simple enough but what is the reality? Those with a specific interest or affinity towards maths or science are committed. However, STEM needs to be taught to the traditionally non engaged student as well (Gonski,et al, 2018). This is where things have been difficult historically. Attracting students who typically struggle with or avoid STEM based education is challenging, particularly where it is difficult to establish relevance. A shift in mindset might be worth considering. Why not determine what interests' students? This is something that has been reported as lacking in many areas of STEM education (McComas *et al*., 2020).

This authors of this paper examined the literature to look at engagement factors with STEM across several variables, using a snowball search of the literature that is initiated by the outcomes of the Gonski review (Gonski et al., 2018). From this, a methodology to examine engagement in STEM has been proposed. To trial the methodology a retrospective analysis of STEMfit, a successful STEM engagement programme (James *et al*., 2020) featured in National Science week (Lee *et al*., 2020) with a disengaged population (Wheeler *et al*., 2020) who had many of the factors of low engagement. The analysis is undertaken to help illuminate and understand better its perceived success.

2. Review of STEM engagement

The priority outcome of the "Gonski Education Report" was to deliver a year of learning for a year of effort in schools through personalised learning (Gonski *et al*., 2018). The report noted the importance of this potential learning regardless of disadvantage. Areas of disadvantage included rural and remote location, Aboriginal and Torres Strait Islander, non-English speaking backgrounds, along with gifted and talented students. These areas of disadvantage seem to be particularly highlighted in STEM areas, when combined with age and historical gender differences (Finkel, 2017). A snowball scan of the literature revealed areas of note within these identified categories.

2.1 Age of decision making

Research shows that interest in STEM at the start of high school is the key predictor of interest in a STEM career when leaving high school (Sadler *et al*., 2011), demonstrating the importance of hooking students in upper primary school on STEM. Furthermore, it is commonly stated that children "are natural scientists" and enjoy observing the world around them (Eshach and Fried, 2005). Can this inbuilt trait be harnessed in all children?. A study undertaken by Microsoft and Harris Interactive found that students became interested in STEM subjects on average, around 8 years of age and it was often a teacher or class that got them interested in the area. However, there needs to be a concerted effort to keep these students engaged, with 57% of students deciding to pursue a STEM degree while in high school. Research indicates that taking higher level maths subjects in high school leads to better outcomes for students in the sciences and engineering (Kaleva *et al*., 2019), yet maths is one of the first subjects that students feel has little relevance with 'real life'. Ensuring that students maintain to see the relevance of STEM throughout their lives should be considered a priority.

2.2 Gifted engagement

Gifted students are recognised as some of the most discriminated against in the Australian school's curriculum (Gonski *et al.*, 2018), unchallenged and often disengaged, sets up lifelong patterns for learning (Gagne, 2011). Gross's (2006) longitudinal study found that in the absence of enrichment, extension or acceleration programs, not only were these members lost as productive members of society but had negative life satisfaction indications such as poor relationships and mental health. Strategies such as vertically integrated curricula, open ended investigation and "passion projects" are a key to engagement (Rogers, 2002) especially in the STEM disciplines which require the early development of critical thinking and formation of a knowledge base.

2.3 Indigenous engagement

Engineering and STEM subjects are generally seen as less relevant within indigenous populations, in part this is due to historical cultural and lifestyle differences where many students desire to express themselves through physical activity, music, or dance which have higher intrinsic satisfaction (Louth *et al.*, 2019). A main driver of learning is student interests which lead to a positive performance in a variety of academic domains (Bonny *et al.*, 2019).

2.4 Gender and STEM

The gender gap is closing in some of the sciences, with observations that females outnumber males in many biology undergraduate science courses. The same cannot be said for engineering, technology and maths. Young females lack exposure to such disciplines and often have limited female STEM role models. Adapting education programmes to encompass areas of high interest for girls, such as enabling them to collect data during movement activities which have been traditionally female dominated e.g. dance, netball, music along with other physical activities increases opportunities for females to engage meaningfully with STEM subjects. At a population level there are pronounced differences in interests, broadly speaking males are interested in things and females in people (Su *et al.*, 2009). STEM engagement is typically based around the technical domain (engineering), rather than the area of application where we see greater gender equivalency (biomedical, allied health university) (Wang *et al.*, 2013) .

2.5 Non English speakers

Conventional educational syllabus in Australia requires understanding high levels of English, thus English as a second language (ESL) students have an additional barrier to learning STEM subjects. Engagement that does not rely on English is an important factor for this sub group (NASEM, 2018). Strategies include the development of "rich contexts" and the understanding that there are two levels of English required, that to communicate socially and then to communicate adequately in the classroom (Hoffman *et al*., 2016). For indigenous students this represents a "double whammy" of barriers to STEM engagement.

2.6 Rural and remote learning

Teaching into rural and remote Australia has always been challenging (Fitzpatrick, 1982). Distance learning is more accessible with the advent of online learning, but issues of engagement remain (Sun and Rueda, 2012). Earlier approaches utilised technology for delivery of learning materials, not as a tool for in-class activities. Furthermore, while technology can breach distance learning issues, not all populations of Outback Australia have access or the capability to undertake these methods of learning. Many remote communities are socially and economically disadvantaged. Many indigenous children grow up speaking the language of their cultural background and experience English for the first time when they commence school (Wigglesworth *et al.*,., 2011). This is likely to hamper children's learning progression, increasing the risk of a child to disengage from learning, especially if the subjects are complex to grasp.

2.7 Verbal ability

Careful examination of factors surrounding STEM engagement reveals that beyond gender, verbal acuity is a significant factor for career choice. Even in the presence of high ability in maths, high verbality was a contra-indicator of a likely choice in STEM careers and engagement. Thus where a student has high maths ability and verbal acuity they are likely to choose something other than STEM, which tends to be a more solitary activity (Wang *et al.*, 2013).

2.8 Use of Technology

The use of emerging technologies in teaching improves learning capabilities of students, especially those that are instructional based (Beavis, 2017; Hendriks, 2016). Furthermore, content appears to be an important learning factor (Peralbo-Uzquiano et al., 2020). It could be assumed if the content was based on information gathered from activities that children themselves undertake, there would be a greater interest during learning processes. However, caution is needed that "just throwing technology" at students in the expectation that learning will come is fraught. Consideration of appropriate technology to best suit the situation and environment should be taken into account. Programs developed at schools to suit the circumstances they encounter is important (Dalziel, 2019). Specifically, it would be highly likely that student interests in a major metropolitan city would be different to a regional city, or remote communities. Therefore, designing technological based teaching and learning applications would need to vary.

2.9 Summary

This short review on factors affecting engagement in STEM reveals that in mainstream education, it is a comparatively narrow "sweet spot" of appeal in students' formative years (primary school) where they engage or disengage in STEM. Gender, socioeconomic advantage, verbal acuity, English speaking skills and domain interest are strong determining factors.

STEMfit undertakes a student centric approach that seeks to engage students through their interest in physical activity and technology. The program has shown success in rural communities with students of considerable socio-economic disadvantage and poor English skills (James *et al*., 2020). However, to confirm that this program is successful in engaging the disengaged a more robust investigation is required to determine what makes it successful.

3. Methodology

Assessment of any STEM intervention requires a mixed methods approach initially capturing baseline data which provides a benchmark for comparing an intervention. To understand the multifaceted aspects associated with STEM success, a range of methods are required to measure participation, engagement, attitudinal changes and learning outcomes (Bernacki *et al*., 2020). Quantitative and qualitative data was gathered and analysed in terms of raising student engagement that may then enhance educational outcomes for students, primarily in the key learning areas of maths and science.

Classroom participation and engagement requires qualitative measures and can include semi structured interviews (Brinkman, 2018) where key themes can be extracted to determine main messages (Riot-Ringuet *et al.*, 2013). While the research reported here did not apply all these processes, it has established a platform for the qualitative research to be applied in subsequent studies. Classroom interactions captured through in-person observations (Miles *et al.*, 2014), examined task related verbal interactions between students and their teacher (King, 1989). Further analysis of classroom communication and classification into distinct groups can help determine both engagement and higher order thinking (Aschner, 1962; Saldana, 2015;). A culturally appropriate form of focus group/semi structured interview, a yarning circle (Dunleavy, 2013) was used to provide insights into the experiences. Data analysis to discover themes would involve manual approaches (Saldana, 2015) to ensure that a depth in understanding of experiences were captured.

While this methodology requires considerable redesign of any educational intervention such as the previously mentioned STEMfit, it can be applied in a retrospective analysis through interview and questioning of stakeholders involved in the prior projects (Lee *et al.*, 2019a, James *et al.*, 2020, Wheeler & Lee, 2020). Activities were carried out in accordance with the Charles Darwin University Human Research Ethics Committee (Approval H18089). The principal cohort reflected on were a group of children from primary school grades 3/4 and 5/6. The age range in these grades were 9 to 12 year olds.

4. Results

In this section we retrospectively examine interviews for a historical STEM intervention entitled STEMfit (Lee *et al.*, 2019a). Beginning in 2016, a pilot programme of introducing technology to the very, very remote communities of the Northern Territory was undertaken by Charles Darwin University to communities approximately 8 hours' drive from Darwin. Observations were made of school children's high level of physical prowess, but low levels of academic achievement, especially in STEM subjects. This resulted in questioning whether children may take greater interest in their learning if it involved something of personal interest. What emerged was a student centric discovery-based programme that utilised wearable technology as a vehicle to capture the student's interest in sport and channel it into an investigation of their own data as engineering problems to solve.

The study was particularly pertinent as the Department of Education - Northern Territory were looking for innovative ways to engage students who had a history of low attendance, were ESL (used their indigenous language at home) and did not feel that STEM activities were particularly relevant to them. The pilot programme engaged males and females alike, increased attendance and interaction in the classroom. This represents a good candidate for a retrospective analysis to help determine the drivers of success in the presence of many of the contraindications of STEM engagement found in the literature review.

4.1 The STEM educational intervention

A variety of sports engineering tools were used by students to quantify their own physical activities. These included inertial sensors, such as found in commercial devices like fitness trackers and smart watches (Lee *et al.*, 2019b), radar guns for speed measurement, light gates for timing information, stop watches and hand-held step counters. This data collection by students allowed rich data sets to be collated for classroom analysis. Data analysis was undertaken using purpose-built spreadsheets where the basic elements of signal processing were introduced to process the time series data to which Newton's laws of motion were applied. Signal processing elements included scaling of data, filtering and thresholding of the inertial time series data which was sampled at 50 Hz. Newton's laws used time of flight data to convert timing information into distance. The analysis is undertaken by the students with the aid of pre-coded processing (using Microsoft VBA inside Excel spreadsheets) to facilitate questioning, experimentation and “play with” their own data. Figure 1 below shows a screenshot of the learning environment.

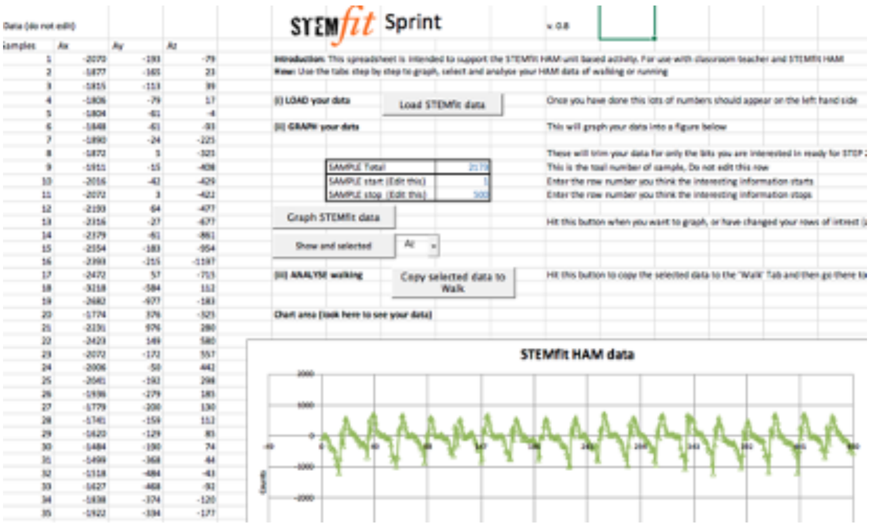

Figure 1: STEMfit time series inertial sensor data, together with vertical channel data (in green) from which students select data of interest and thresholds to count steps taken in a run, stride length and calculate running speed.

4.2 Retrospective Analysis

In a semi-structured interview of a school’s leadership team who were involved in the STEMfit pilot trial, the following qualitative information was gathered.

Participation

- Feedback: If you are a remote indigenous kid not only is it [learning] boring, it's normally very negative [hearing what is said inside schools, away from schools, on TV etc] e.g. infant mortality, adult mortality, incarceration, reading levels, unemployment [therefore] in most cases, data means "bad news".

This indicates that children are continually bombarded with negative information about themselves and their culture. This is hardly an environment that would foster engagement and enquiry-based learning. Others have highlighted the need for authentic and relatable situations that are student centric and where the inquiry process builds confidence in learning (Willms, 2003). Once children were shown their data, they made comments such as: “*Let me have another go, I can go faster (or throw further, or jump higher)*”, “*How fast was my throw?*”.

Engagement

- Feedback: When kids engaged with STEMfit they capture data that is instant, about them, it's presented in a positive way e.g. "you ran the 40 [m] in 6.5 seconds" and most importantly, they can directly influence the data.

Meaningful data collected and taken into a class and used appears to be powerful in several ways. The data is relevant to the child, it is relatively fresh in their minds and they can be guided by themselves or the teacher with “what if” questions. Typical questions came from children participating in some of the running data collection were: “*I am faster than other kids around the world*” (after they were shown data from overseas studies), “*Can I jump in a different way to go higher?*”, “*What if I ran with the wind?*”. Other situations have evoked passionate debates. For example, one girl questioned whether her jump height should not be at the point of leaving the trampoline mat, but at the deepest point where the mat had compressed too.

Attitudinal changes

- Feedback: Kids with no previous interest in numeracy and data are suddenly saying "can I have another go?" and "what was my time?", "I was faster this time!". [Therefore] they naturally start analysing data.

Children started to ask questions relating to the activity completed. For example, one child was capable of fast speeds when running in a straight line. However, in an agility run, his score was less than he expected, prompting the student to question whether the system was accurate. A discussion of what is agility and the need to exercise in a particular way ensued. Further questioning and discussion allowed for deeper thought processing. Questions coming from children that can be used to further challenge their thoughts. For example: "*Taller kids can reach up higher than short kids, is that fair?*". This then opens up other concepts related to measures and analysis with leading questions such as: "*Did the bigger kids always jump higher than the little kids?*" As with jumping, children were also interested in their own running data. However, greater interest came when average data from children from other countries were displayed on the same Figure. This was followed by adding a famous runner's (Usain Bolt) 40 m sprint time. These additions gave children some context and perspectives of where their own data stood. This appeared to be a powerful motivator to engage. Due to it relating to themselves, it was also tangible to the children and not from some abstract unrelatable scenario.

Learning outcomes

- Feedback: A comment from a school principal regarding engagement and attitudinal change: "*Something teachers have been trying to get them to do since Noah was a boy*".

This comment and student feedback indicate that the engagement is organic and attitudinal change largely intrinsic. Instead of learning from a (rhetorical) textbook, which is often perceived as boring, dry and removed from the concepts that children encounter themselves, they became immersed in the data because it is about them.

It is often seen that children lose interest if a question or answer does not make sense e.g. if an answer to an average calculation is that two people own 2½ horses each; if a child has not learnt the concepts of what an average is, a typical response is: "*That cannot happen, half a horse is a dead horse.*" Then the disengagement continues through a cycle of negative information, non-contextual learning materials, and outputs that make little sense to children struggling to learn. STEMfit appears to offer opportunities to break this cycle through children learning about themselves where the data is positive. Previous research has shown that teachers have already developed teaching practices around student abilities to enhance student engagement (Kamler and Comber, 2005). Combining the outcomes of this previous research with our observations presented here shows strong indications of engaging children by utilising various technologies for data collection of children's movement activities and taking that into the classroom for their STEM subjects.

5. Conclusions

This paper has investigated the various factors that contribute to engagement in STEM activities finding that gender, socio economic disadvantage and lack of challenge in areas of relevance are significant factors. Focusing on the STEM domain rather than areas of application that narrows STEM appeal. The vitality of STEM engagement in a verbal context is critical to drawing in those from socio economic disadvantage, poor English-speaking background, and those with low verbal acuity. There was a high degree of anecdotal equivalency between the literature review and a retrospective analysis of a STEM programme that sought to target children's interest in physical activity. Sport and physical prowess are often popular amongst the STEM disengaged and represents a good strategy for future engagement.

This is an important signpost for future work in this area which is hoped to support current Government priorities in STEM education as a key to future economic success.

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