Building confidence in STEM students through breaking (unseen) barriers

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Abstract.

Science, technology, engineering, and math (STEM) subjects have historically struggled to be inclusive and accessible to students from diverse backgrounds. The field of geoscience, in particular, has also had challenges in diversity with respect to staff and student recruitment. The consequence of non-inclusive practices still propagates today, with certain demographics not engaging in STEM activities. As a result, there needs to be conscious efforts to adopt equity, diversity, and inclusive (EDI) initiatives for subjects such as geoscience to grow. In this article, we outline the steps we have taken to break down known (and unknown) barriers to education in the teaching of a science outreach course to a diverse student body. Our outreach course, Think Like A Scientist, has been running in a number of English prisons since 2019. Although the program is tailored to the restrictive prison environment, the application of its core principles to education are fundamental EDI practises that could be beneficial to a wide audience. In this paper, we outline our reasoning for specific pedagogical choices in the classroom when working with students that have low confidence in STEM education, and highlight the need for engagement that is relatable, accessible, inclusive, and offers encouragement.

1 Introduction

A student's low confidence in their own ability can lead to non-engagement (e.g., low self-agency) in the classroom (Angus et al., 2008; Legault et al., 2006; Statistics Canada, 2002). In particular, science, technology, engineering, and math (STEM) subjects have shown to generate negativity amongst students (Holmes et al., 2018), with the reasons behind such low self-agency being multifactorial. For instance, critical educational neuropsychological research (Billington, 2017; Damasio, 2000) has indicated how social, emotional, and cultural factors impacting disadvantaged students cannot be separated from a student's cognitive ability to learn within formal environments. Furthermore, research suggests that students who believe themselves not to 'fit' into educational settings are more likely to perform poorly or withdraw, due to the impression they do not match the profile of students who usually succeed (e.g., 'stereotype threat', Steele and Aronson (1995); Pennington et al. (2016)). This can be due to feelings of stigma (or 'minority stress', Meyer (1995); Parker and Jones (1999)) that relate to race, religion, disability, economic status, sexuality, gender, or other intersecting cultural factors (Dowey et al., 2021). This stigma can also be subtly reinforced in the language and hierarchies used in STEM classroom settings.

In this short commentary, we discuss a framework put in place to build student self-agency during the teaching of a STEM course in English prisons in 2019 (Heron, 2019, 2020). The course, called 'Think Like A Scientist', was designed to improve critical thinking and encourage independent thought for students. The program, the first of its kind in England, used short, impactful talks on science topics to bring new information to the class (where a number of subjects were geoscience focused, such as climate change, plate tectonics, natural hazards, and space missions). Students participated in seven different 2.5 hour sessions and were encouraged to do assignments each week.

For prison learning, education and employment have been highlighted by the UK Government's Ministry of Justice as key points in reducing re-offending rates (Coates, 2016). However, due to restrictive prison environments (Rogers et al., 2014; O'Brien et al., 2021), a lack of funding for prison educational programs, and (most importantly) the impact of prisoners' previous struggles with traditional classroom settings (Harlow, 2003), teaching in prison is a complex endeavour. As such, educational needs are largely unmet for those in custody (Geib et al., 2011).

To overcome these obstacles, a key component of our teaching in prison was to align education to the needs of students that are harder to reach, rather than students adapting to the pace and structure of an inflexible education program (von Stumm and Wertz, 2021). As a result, the focus of our course was to act as a stepping-stone to more formal education (e.g., high school diplomas and undergraduate courses) through increasing student self-agency in the short and long-term. The method we implemented follows that course content be relatable, accessible, inclusive, and offer encouragement (RAIE method).

2 Relatable

By visiting successful prison education programs during the development of our course, it was clear that learners engaged best when the material was relatable (e.g., classes related to criminology and law) (King et al., 2018). This posed a challenge for more abstract STEM fields, that appeared to be far from normal day-to-day life. Furthermore, as mentioned above regarding 'stereotype threat' (Steele and Aronson, 1995; Pennington et al., 2016), potential students also may find the scientists themselves difficult to relate to (e.g., coming from a 'ivory tower').

Although some of the course had material that is directly applicable to every day life (e.g., sleep and climate change), the majority of topics taught were not immediately relatable (e.g., space missions to Mars, earthquakes, robotics, the universe). However, to bridge the gap between student and STEM content, the course focused on how we *think* about a subject - a process which is inherently relatable. Instead of a standard passage of information from teacher to student, our course taught the 'the scientific method' (Figure 1) as a framework where students explore what they *do not know* about a subject and discuss how we can find out more. This method has been shown to improving critical thinking among students (Davenport Huyer et al., 2020).

For instance, each session starts by asking the group to list anything related to the main topic (e.g., what do we know about the solar system?). From here we can understand the key areas to focus on and ask how we can find that out (e.g., Do we need to visit Mars to check for life? Can we send robots? What would they look like? How would they work?).

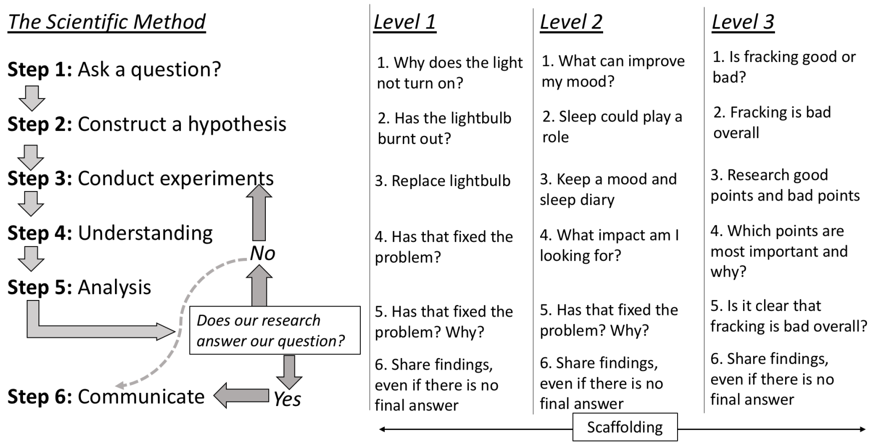

Figure 1. The scientific method and examples. A framework for conducting scientific research is known as 'the scientific method'. All scientific studies follows these basic principles, but they are applicable to everyday activities and can be used to improve critical thinking. Examples show scaffolding technique to build up the levels of questioning (e.g., Vygotsky's sociocultural theory and his learning concept of the Zone of Proximal Development (ZPD), Berk and Winsler (1995)). An important part is to understand that a negative result (e.g., not fully understanding a problem) is part of the process and can also be communicated.

By shifting the focus of the program to be about how we think about a subject rather than what we know, the material is applicable to everyone. Crucially, this creates an open structure, rewarding exploration and engagement over attainment, suggested to be positive for all learners' self-esteem and progression (Ustun and Eryilmaz, 2018; Saloviita, 2020; Hornby, 2020).

3 Accessible

A key part of our course is that it is not taught in the standard education classrooms - an arena where many of the target students have had previous negative experiences. A common place to hold the course is in the library, which is not only sufficiently neutral ground to engage difficult to reach learners, but is also often carpeted to help with any sensory issues (Craswell et al., 2021). The threshold of a traditional classroom could be an unseen barrier to a student accessing education - a scenario that can be widely applied (e.g., students from low-economic backgrounds not wanting to engage in a outreach event held in a 14th Century Russell Group college).

Recent critical education (Greenstein, 2015) and critical disability (Goodley et al., 2018) literature references mainstream education 'norms' throughout the Global North. These norms, often internalised and maintained subconsciously, may subtly and or more explicitly celebrate an 'idealised' learner inhabiting a particular demographic, societal status, and learning profile; one who successfully progresses through a curriculum and pedagogy without requiring adaptation, who is not disabled or

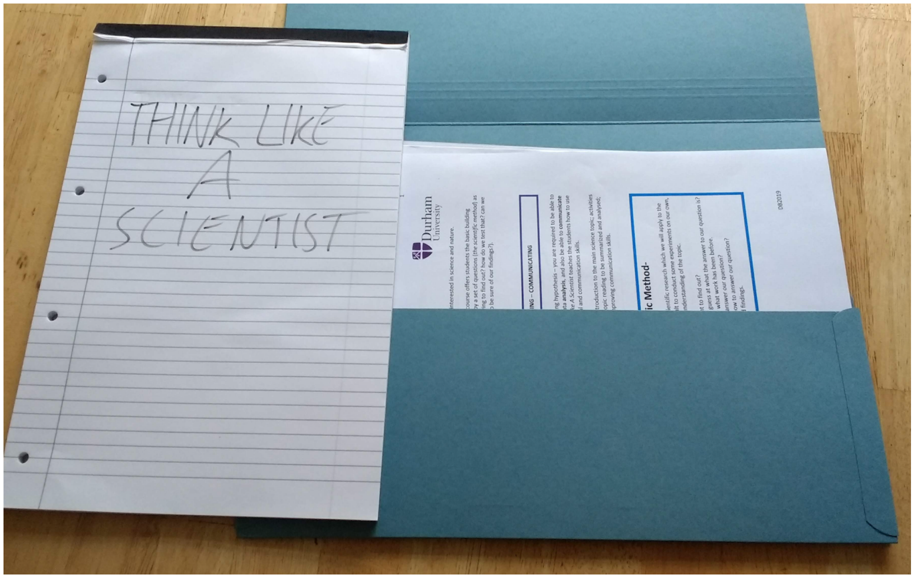

Figure 2. Accessible teaching. By making the equipment requirements for the course as basic as possible, there were no barriers to students accessing education resources. In Think Like A Scientist, only pen and paper were required.

neurodivergent, is without learning differences, and who effortlessly relates to the prevalent cultural meanings and values of their educators (Greenstein, 2015; Goodley et al., 2018).

A challenge here was to create course content that celebrated each student individually, rather than revert to our mainstream education norms. For a behavioural, cognitive, and emotional engagement to be achieved for all learners, an open and dynamic teacher-learner relationship must be fostered, built upon sensitive understanding (and adjustment) to a learner's needs and social contexts (Darling-Hammond et al., 2020; Breakey, 2006; Sanger, 2020). In the preparation of course material, it was important to simply acknowledge the intersectionality of potential students and change the expectation of each submission of work based on the learner's needs. In class, the instructor would acknowledge that each student can bring individuality to the course through the open questions on scientific topics (see Inclusivity section). In addition, small acts of flattening the power dynamic within the prison environment can help to nurture a supportive learning landscape (e.g., making a coffee for students during the break).

We also considered a number of points related to language. Resources whilst teaching in prison are scarce, and often the only teaching aid available (apart from a pen and paper, Figure 2) is language (which turns out to be key). If the language used was terminology heavy or uses allegory, metaphor, or other forms of figurative or culturally specific language, this may have been difficult to process for many students. Potentially, this may have disadvantaged autistic students, or those with learning differences (Kalandadze et al., 2018). A positive step was to implement 'Plain Speak' English for universal accessibility, which meant using language and design strategies that make texts easier for target audiences to understand and use (Mazur, 2000; Garwood, 2014). In practice, this means not using technical words without a proper introduction. An example for discussing different types of volcanoes would be to avoid using the word viscosity in the initial comments, opting for ‘runny’ or ‘thick’ until low and high viscosity can be scaffolded in (Berk and Winsler, 1995).

The impact of applying plain language from the start of a course is to allow students to be clear on the content immediately when it is presented, rather than not being unable to understand a technical work and potentially derailing the learning experience. Applying plain language has been beneficial in the medical profession when communicating care to patients (Warde et al., 2018; Sagi et al., 2021) and we create similarly accessible content through using plain language summaries of scientific research (such as the online magazine The Conversation). We also follow up with taking into consideration who and what was rewarded and prioritised in interactions with students (e.g., are we celebrating getting a correct answer or for asking a question of clarification?).

Furthermore, we taught practical examples of science in action to connect the student to the educational content through material relevant to cultural and life experiences (Cents-Boonstra et al., 2021). An example being discussing climate change with reference to the impact of food choices (as this is something that is done every day), or using a natural hazard that captured the public’s attention to introduce plate tectonic processes (e.g., Iceland’s Eyjafjallajökul volcanic eruption of 2010 or Hunga-Tonga eruption and tsunami of 2022).

Many learners will continue to be excluded from learning opportunities in any classroom setting that doesn’t take into consideration these accessibility issues, impacting not only their educational and professional progress but also their mental wealth and wellbeing (Tejerina-Arreal et al., 2020).

4 Inclusive

Although a certificate from a university is offered on completion of our course, there was no formal assessment strategy linked to the program. By breaking down the barrier of grading, an environment of open expression could begin to be created and allow for more potential students to engage. Through the main focus of the course being on how an individual’s mind works to tackle a problem, we were able to tailor the learning experience and bring education to the student (von Stumm and Wertz, 2021).

Group discussion of opinions on topics are fundamental to the class (Pompa, 2013). In our course, students were often asked to give their thoughts on current topics (after reading recent research) with which there is no scientific consensus (e.g., should we colonize Mars? Is there life outside our Solar System?). As there is no right or wrong answer, the students were given a voice on cutting edge science - the impact on student’s self-agency can be significant (Figure 3).

These two strategies (e.g., not implementing formal examinations and asking ‘open’ questions) produces a flattening of the power dynamic as compared to a traditional classroom. Linking to the previously mentioned theories on ‘stereotype threat’ (e.g., fear or anxiety of confirming a negative stereotype about one’s social group, Steele and Aronson (1995)) and ‘minority stress’ (e.g., stress faced by members of stigmatized minority groups), implementing these strategies could remove critical barriers to students’ learning (which teachers may or may not be aware of). Indeed, it has been recently highlighted that inclusive science communication could be crucial in addressing the systemic problems of inequitable access to (and engagement with)

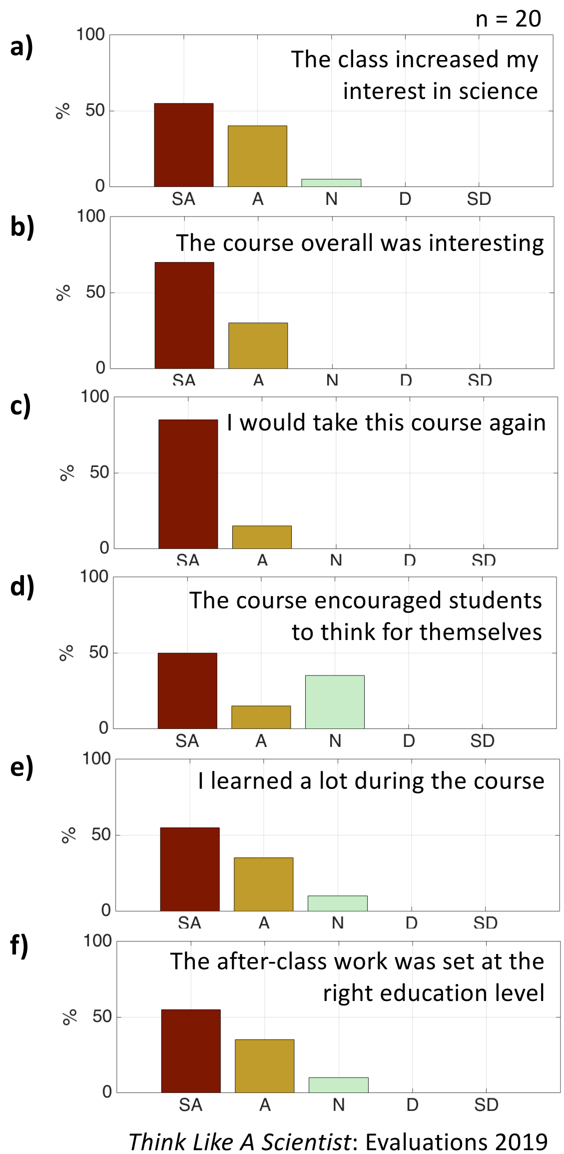

Figure 3. Student feedback on selected post-course questions. Full feedback from three courses are provided in the supplementary material alongside pre- and post-course student questionnaire templates. Abbreviations stand for Strongly Agree (SA), Agree (A), Neutral (N), Disagree (D), Strongly Disagree (SD).

STEMM (science, technology, engineering, mathematics, and medicine) subjects (Canfield et al., 2020). Careful thought is required when creating content and engaging students if we would like to reach diverse audiences (Canfield et al., 2020).

5 Encouragement

From the classes taught in prison, not all students feel comfortable in writing down their thoughts and submitting work. However, for those that do, the work is ‘marked’ by highlighting the main points of their discussion and offering encouragement. Here, it was important to ignore spelling and grammar errors, and focus on the positive aspect of the student submitting thoughts and ideas (as discussed in Accessibility section).

Incidentally, by setting a task to express their thought process, rather than ‘testable’ questions, the work submitted not only reflected upon the subject matter, but also their personal experiences with the topic. For those who submit, the feedback can be “like receiving a prize” as one student wrote in the course evaluation.

6 Conclusions

In this article, we have outlined our process for teaching STEM to students with unseen barriers to access their education pathway. Even though our course was designed with the restrictive and complex prison education system in mind, there is a wider application to this work specifically in settings where students are not engaging in formal education due to low self-agency. Examples could be in running an outreach event or open day to students who encounter barriers due to their race, religion, disability, economic status, sexuality, gender or other intersecting cultural factors.

We outline below a potential framework for breaking down educational barriers for students who (traditionally) do not engage:

– create a neutral classroom dynamic (in location and environment);

– have the class focus on dialogue;

– produce content that is relatable to everyday life;

– remove the grading structure (where possible);

– avoiding assumed previous knowledge;

– avoid asking explicitly worded questions;

– ask questions with no scientific consensus to generate discussion;

– implement clean ’Plain Speak’ English;

– and emphasise encouragement when marking submitted work.

This framework produces dialogue focused course that is relatable, accessible, inclusive, and offers encouragement (RAIE method), which can allow students to build self-agency when learning STEM subjects.

Data availability. Student feedback from three courses are available as supplementary information, alongside the pre-course and post-course questionnaire templates.

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