Widening participation and success in STEM: embedding research-engaged practice to measure impact

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Abstract There is a systemic shortage in the number of graduates entering the STEM workforce. To address the current graduate shortage (HM Govt, 2017), the widening gap between industry demand, the available skilled workforce (ASE, 2020), and the underrepresentation of key groups within STEM industries and academia requires overhauling the STEM education 'pipeline'. However, there is a lack of consensus on how to increase the diversity of students pursuing STEM post-16 and how to tackle the dual challenges of engagement and science capital for the most underrepresented groups. This paper discusses the development of a research-engaged sustained STEM outreach programme working with students from rural and coastal schools in South-East England. Whilst there are numerous STEM programmes that aim to provide academic support, build science capital or improve diversity in post-16 STEM studies, this paper describes how two areas of innovative practice came together in a university-led pre-entry STEM widening participation programme: Inspiring Minds. The first relates to its foundation in a research-engaged pedagogy (the epistemic insight curriculum) that underpinned the programme content and design, and the second to the embedded approach to rigorous evaluation and impact monitoring tracking shifts in both aspirational and attainment measures of participating students.

Key words Epistemic insight, evaluation, STEM education, sustained engagement, widening participation

Introduction

Despite agreement that there is a problem with recruitment diversity in Science, Technology, Engineering and Maths (STEM), there is a lack of clarity on how to encourage greater representation and uptake of STEM in higher education (HE). The divide appears as early as Key Stage 1 (age 5–7) (ASE, 2018), and continues through to GCSE choices where learners are three times less likely to take triple science[i] (Archer et al., 2016, p. 302) therefore influencing the STEM educational opportunities open to them post-16.

The Inspiring Minds Programme (IMP)[ii] was designed to address the need for an intervention that moved beyond the *knowledge application* model of STEM outreach. Such approaches focus on students applying existing curriculum knowledge to a new situation (e.g. to design a rocket). Whilst this can deepen students' understanding of specific concepts, it requires students to have a firm grasp of the theory to access the activity. This can lead to students having their perception that STEM is 'not for them' compounded if they have limited understanding of the knowledge being applied.

In contrast to knowledge application, the *knowledge generation* outreach model enables students to generate STEM knowledge that is *new to them*. This avoids students not being able to access the activity but can make the interaction content-heavy and context-light. Research shows effective STEM engagement needs to move away from replicating the content-heavy model in schools to a 'context-heavy' approach (Schwartz, Lederman and Crawford, 2004). The interdisciplinarity of IMP capitalised on the university's Epistemic Insight Initiative's[iii] STEM innovation research. The Initiative's curriculum framework focuses on developing students' epistemic insight by equipping them to understand the similarities and differences between disciplines' preferred methods, questions and norms of thought. When placed within a widening participation context, it supports the development of students' academic confidence and science/cultural capital by drawing on their prior cross-disciplinary knowledge to (re-)engage with STEM. The framework creates a level playing field by empowering students' context-rich agentic learning via philosophical 'big questions'.

This paper invites us to consider how we can critically reform the STEM outreach offer to disrupt the perceived narrative around the 'kinds' of people who take up STEM and support the most underrepresented to be confident scholars. First, we discuss the underpinning curriculum framework that could be used across a range of educational and widening participation activities. Second, we discuss our approach to working collaboratively to embed rigorous evaluation into the programme design. Finally, we briefly discuss the results and recommendations for wider practice.

Before embarking on the detail, it is important to establish how 'aspiration raising' is used within this article and research. The use of 'aspiration raising' language in relation to outreach stems from the AimHigher[iv] scheme which ran in England from 2004 to 2011 and is still used within some UniConnect Partnerships. However, the rhetoric of 'low aspirations' to explain inequality in educational attainment and progression rates means it has become a contested term (see e.g. Harrison and Waller, 2018). Within this research, 'aspiration' has been used as shorthand for a combination of attitudes that relate to students' self-perception and self-efficacy. This includes attitudinal shifts that university is for people 'like them', academic confidence in their own ability to reach and succeed at university, and the extent to which students' feel they are empowered or equipped to realise their aspirations. Every student is aspirational but by environment or other pressures they might not feel that their aspirations are achievable. 'Aspiration raising' in the context of this article refers to work that enables the student's existing aspirations, including the provision of information about how to achieve their goals and building academic confidence and resilience.

Research-engaged pedagogy

To overcome findings by Barmby, Kind and Jones (2008), that students' (ages 11–14) attitude towards science declines as they progress through secondary school (ages 11–16), STEM outreach needs to stop replicating the school experience and focus on conveying the 'wider relevance' to 'help foster students' interest in and perceived utility of science, which may then encourage aspirations towards science careers' (Sheldrake, Mujtaba and Reiss, 2017, p. 171). Whilst the evidence for outreach activities improving progression is mixed (Banerjee, 2017), it does suggest conveying wider relevance can help foster students' interest in science (Sheldrake, Mujtaba and Reiss, 2017) and this can support students to deepen their understanding of the nature of scientific practices (Allchin, 2013).

Inspiring Minds is an informal STEM programme designed to positively impact students' attitudes and aspiration towards STEM and HE. The collaboration between the University's School and College Engagement (SCE) team and the Learning about Science and Religion (LASAR) Research Centre at Canterbury Christ Church University, instigated by SCE, capitalised on joint expertise to create an academically rigorous programme. LASAR were researching science education and subject compartmentalisation and IMP provided opportunity for both teams to gain a richer understanding into (a) the applicability of epistemic insight in informal contexts and (b) the impacts of an interdisciplinary approach to STEM on students' attitudes.

The Learning about Science and Religion Research Centre showed entrenched subject compartmentalisation caused students difficulties in recognising the relationships between STEM and humanities. This is also highlighted in the literature, identifying early adoption of STEM being 'for' or 'not for' people 'like me'. Epistemic insight provided the catalyst for developing a programme that appealed to those who wouldn't traditionally volunteer for STEM activities. The Inspiring Minds Programme was designed not to tell students what they 'needed' to know to 'catch up' but inspire and engage them through familiar ideas that sat outside the core curriculum, and importantly value the students and their existing knowledge (including non-STEM).

An epistemically insightful approach to learning supports students to recognise and investigate the links between disciplines and develop their understanding of how knowledge is formed.

> 'Focusing on epistemic insight … engenders a pragmatic approach to helping students make better sense of the message they receive in different subjects about scholarship and how claims are tested' (Billingsley and Hardman, 2018).

Considered in connection with science capital research (Hitchin, Horvath and Petie, 2017), students from low participation backgrounds are far less likely to have opportunities to develop their understanding of science in interdisciplinary contexts. Therefore, the IMP curriculum was framed around four philosophical questions that could be informed by scientific investigation to enable students to develop their understanding of the nature of science whilst offering an alternative to the close-ended epistemic processes modelled within formal science learning. Close-ended processes require students to find a single 'right' answer which can lead to students feeling under pressure and fearing 'getting it wrong' which can negatively impact engagement (Allchin, 2013) and confidence. The IMP aimed to develop students' understanding of the power and limitations of scientific knowledge. Thus, the IMP curriculum didn't simply provide students with scientific content, but also engaged them in discussions around the nature and role of science in social contexts.

The epistemic insight curriculum is innovative in its focus on multidisciplinary big questions. Students can access the STEM activities (including the Association for Science Education's CREST award) through application of their existing knowledge in science and (as importantly) other disciplines. The curriculum provides multiple access points due to the multidisciplinary framework. Therefore, students are presented with an opportunity to apply their existing knowledge and engage with knowledge generation. For some, knowledge generation is through the development of their STEM content knowledge, whereas for others it is through developing their epistemic awareness of the links between, and powers/limitations of, different disciplines.

Innovative evaluation practice

The IMP was based on a hypothesis testing methodology: students become disengaged from STEM because it feels irrelevant, and this is compounded by the compartmentalised STEM experience in school. If the hypothesis is correct changing the contextual framework of science and/or highlighting interdisciplinary relationships should improve student engagement. The evaluation model for the IMP was designed to inform future delivery and support the Epistemic Insight Initiative. The programme also aimed to buck the Barmby et al. trend. These aims sat alongside the need for evaluation against Office for Students (OfS) metrics on students' aspirations and attitudes towards HE. The theory of change fell into two broad strands: (1) could the IMP change students' attitudes to STEM?

and (2) could sustained engagement with the IMP positively impact students' aspirations and attitudes to HE study? To evaluate the success of the programme, detailed baseline surveys were completed at the first session. The survey included questions adapted from the Barmby study (using STEM, not just science); questions validated by CfE (Centre for Evaluation) on attitudes and aspiration for HE; and questions addressing students' understanding of the relationships between science and other disciplines. The evaluation of pre and post survey data, alongside student interviews, showed positive shifts countering the Barmby trend, with statistically significant increases in participants' intentions to study STEM post-16 and attend university (Lawson *et al.*, 2019, 2020; 2021). Whilst these findings supported the iterative evaluation of the IMP, we were aware of a potentially expanding divide between their IMP engagement in Year 10, and it being sustained into their terminal examinations and post-16 choices. Furthermore, there was a potential gap between intentions and their realisation via exam attainment. The next stage of evaluation sought to understand whether there was sustained impact on aspiration, and if any attitudinal shifts had, potentially, increased attainment (a key priority for education policy in England (HM Govt, 2022)).

The challenge was to provide robust evidence suggesting a causal relationship between the IMP and the outcomes. Following Office for Students' guidance on credible evidence (OfS, 2019), we undertook a quasi-experimental evaluation, whereby IMP participants were matched to non-participants based on confounding variables known to influence Key Stage 4 attainment. Following the publication of examination data for the first IMP cohort, the team worked with colleagues at Higher Education Access Tracker (HEAT) to match non-participants to establish impact in relation to attainment, and provide a case study of how HEAT can be used for robust evaluation (see Anthony, 2022).

The IMP was carefully targeted, offered to the most educationally disadvantaged learners, and students were invited to participate. This meant a comparator group of students wasn't 'created' at the time of the intervention (four years prior to the attainment evaluation process[v]). Owing to a well-established partnership with Kent and Medway Progression Federation[vi]

(KMPF), there is a tradition of large-scale data sharing. With students' permission, records are tracked (by HEAT) into the Department for Education's (DfE) National Pupil Database to obtain Key Stage 4 exam results. Therefore, it was possible to use non-participant baselined students who had received no or only light touch activities (less than an hour). Non-participants were therefore not non-participants of any outreach activity, but rather non-participants of the IMP and other intensive or sustained activities.

This data sharing process meant it was possible to form a comparator group of non-participants that were as similar as possible to the participants on observed variables. This retrospective creation of a comparator group moved the standard of evidence from Type 2 to Type 3: 'We believe our intervention causes improvement and can demonstrate the difference against a control or comparison group' (OfS, 2019, p. 11).

Results and recommendations

The analysis found that the IMP participants achieved higher Attainment 8 scores than the matched non-participants, achieving an average of six grades higher across eight core subjects. This result was significant at $p<.10$. Further participants were +26 percentage points more likely to achieve a 9 to 4 pass in Maths (64%) than the non-participant group (38%). This result was significant at $p<.05$.

Previous analysis by HEAT into the relationship between outreach and attainment (Anthony, 2021) showed that students' prior attainment at Key Stage 2[vii] accounts for 42.7% of the variance in Attainment 8 scores. Measures for socio-economic background only explain a further 11%. Therefore, Key Stage 2 attainment data is the biggest predictor of future attainment at Key Stage 4. Key Stage 2 data is made available alongside the Key Stage 4 data, enabling us to compare participant and non-participant groups. Both groups contained students across all three Key Stage 2 attainment bands: 'Low' (below Level 4), 'Medium' (at Level 4) and 'High' (above Level 4)[viii]. However, participants had lower Key Stage 2 attainment compared with non-participants (45% to 21% at 'low' Key Stage 2 attainment). This means we can be more confident that participating in the IMP raised students' Key Stage 4 attainment, as this difference cannot be attributed to higher baseline attainment. Rather, participants had 'further to travel' having started from a lower level at Key Stage 2.

In addition to the attainment data, qualitative data was collected via survey questions and semi-structured interviews. These took place during each cohort, and via reengagement with cohorts one to five, two years after cohort one completed the IMP. Although the questions didn't directly address attainment, they provide evidence of impact around aspirations and academic confidence. We include some data here to highlight the breadth of the evidence base.

The initial interviews repeatedly highlighted the IMP's value regarding opportunities for autonomous learning and improved confidence. Some students also noted impacts on their school-based learning, making use of the skills to complete (non-STEM) homework 'instead of just copying from the textbook' (student O). Or identifying combining the group's research and 'going away and looking at different sources' (student H) as new learning opportunities. Others highlighted the achievement or enjoyment of having the freedom to 'do our own research and find out our own stuff' (student E) which was often placed in comparison to school science. One student went as far as saying 'I found it easier [on Inspiring Minds] because we weren't being spoon fed but were given the information in ways we understand' (student B).

This increase in confidence and awareness of their own abilities was common across participants and teachers. Students reported that,

> '[IMP has] opened me up and I'm a bit more comfortable […] in talking to people about certain things' (student O);
>
> 'I was a bit nervous at first but then when you got in to it, it was easier' (student I);
>
> 'It definitely helped me with my confidence […] and I'd say I'm a lot better at working in teams [than before IMP]' (student H).

Particularly striking was a teacher interviewed in September following engagement with the IMP in the previous academic year where they reported participants seemed determined and more aware of their post-16 opportunities, with 'greater awareness of themselves and what they're capable of' (teacher C). At the point of the reengagement survey (cohort one students were in Year 12[ix]), 78% of all students could exemplify how participating in the IMP had improved their engagement, understanding or participation in school science. Of those in post-16 education, 43% were studying at least one STEM-based subject, and of those who were pre-16, 46% intended to study at least one STEM-based subject post-16.

Whilst brief, these highlights from the data show the power of the IMP to enable the aspirations of the young people who take part by increasing their academic confidence, resilience (which is borne out in the wider data) and self-efficacy. As noted at the start, the premise was not that these students lacked aspiration but that some lacked the tools and/or confidence to know how to achieve their aims.

Whilst further work needs to be undertaken to establish which aspects of the IMP had the greatest impact on student success, we argue that the use of sustained interdisciplinary programmes for STEM engagement supports increased attainment and aspiration of participants. This requires a shift in our approach to widening participation practice, placing greater emphasis on sustained engagement and impact over volume of reach. In addition, as identified in the opening section, low HE progression rates are often not due to lack of aspiration, but lack of the information, tools and skills to actualise that aspiration. Therefore, there is important further research needed to understand how and where sustained programmes are impacting on students' ability to actualise their aspirations and which skills and so on have the greatest impact on students' progression routes.

Furthermore, it requires close working with schools/colleges and partners such as HEAT to establish comparator groups, at least retrospectively, but ideally working with schools to establish comparator groups at the time of the intervention. The involvement of schools supports the creation of comparator groups that are matched on traditional social metrics (e.g. Index of Multiple Deprivation[x] or HE Participation rates) and characteristics such as school attendance or parental engagement. This means students can be matched as closely as possible on observed and unobserved variables. This is not a Randomised Control (RCT) evaluation, as non-participating students still receive an intervention. However, the use of closely matched comparator groups and the considered placement of data collection points mean that such evaluations can mimic the positive aspects of RCTs whilst avoiding the ethical and practical issues that are inherent in educational Randomised Control Trials. This level of evaluation supports schools and HEIs to understand where and how limited resources can have the greatest impact. However, evaluation must be built into the programme design.

Conclusion

The aim of the IMP was to build aspiration and confidence in Year 10 pupils around STEM and HE. The data shows the IMP went further and impacted on attainment. However, this level of data and success is only possible due to two key partnerships. The first is capitalising on access to educational research at Canterbury Christ Church University (and other institutions) to understand where there were evidenced barriers to student success. This evidence-informed approach is available to all widening participation teams, but we must build a greater body of evidence around what works (for different disciplines, underrepresented groups, access to and success in HE, etc.). This leads to the second partnership and working with organisations like HEAT, the KMPF and partner schools/colleges to gather robust evidence on the impact of the interventions. This takes a sector-wide commitment to be research-engaged, share best practice, and work in partnership to understand, for example, if the IMP can have the same impact with inner city students in Birmingham, or rural students in Scotland, as it has had with rural and coastal students in South-East England. It requires a united commitment 'towards ensuring that every young person […] who has the potential to benefit from higher education (HE) – particularly those currently under-represented – is aware of the opportunities available and can make an informed choice about their future' (KMPF, 2022) and has access to opportunities that support them in this goal.

[i] In England students studying GCSE science either take 'double' or combined award science. Combined science is worth two GCSEs, whereas for 'triple science' they receive a terminal qualification in each of the three sciences separately. Triple science is often recommended for those seeking to pursue the sciences at post-16.
[ii] Inspiring Minds received sustained funding from OfS (Office for Students) via the UniConnect programme.
[iii] Funded by Templeton World Charitable Foundation (Grant: 0225).
[iv] AimHigher was an umbrella term to describe initiatives aimed at widening participation in higher education in the UK. AimHigher ran from 2004 to 2011 and was funded by central government. Uni Connect was formed in 2017 with similar aims to AimHigher and works across 29 partnerships of universities, colleges and other local partners to offer activities, information, advice and guidance on progression to university or college.
[v] This is due to the delay between student attainment data being produced and it being made available to HEAT for analysis by the Department for Education.
[vi] KMPF was originally established in 2011 when the government's national AimHigher programme came to an end. Canterbury Christ Church University and the University of Kent funded the formation of the KMPF as an ongoing commitment to widening participation in Kent and Medway; it was one of a handful of remaining partnerships in the country to continue after the conclusion of government funding 2011.
[vii] There are two points of compulsory standardised assessment within the English education system. Each occurring at the transition between education stage. The first is at the end of primary schooling (age 10). This Key Stage 2 data provides secondary schools with a baseline of students' prior attainment. The second is at the end of Key Stage 4 (age 16) before students move into further education. Assessment between further and higher education is dependent upon the education pathway chosen and is therefore not compulsory.
[viii] The Key Stage 2 data provides a scaled score for students' achievement that indicates whether they have reached the expected standard for their age. They are used to measure a child's progress against other pupils of the same age, across the country, and provide an indication of their expected achievement at 16. A 'Level 4' is the expected level students should achieve by the end of Key Stage 2. An average 75% of students achieve an 'on target' Level 4, approximately 11% will exceed this at level 5 or 6; therefore approximately 14% students will not reach the expected standard.
[ix] Year 12 is the first year of Key Stage 5/post-16 study.
[x] The Index of Multiple Deprivation (IMD) measure relative deprivation (in small areas) across each of the UK nations. Areas are ranked from the most deprived area (rank 1) to the least deprived area.

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