Inspiring minds: How big questions can build students' epistemic insight and improve attitudes towards STEM

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Title: Inspiring Minds: How Big Questions can build students' epistemic insight and improve attitudes towards STEM

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Key words: informal science learning (ISL); epistemic insight; widening participation

Brief description (30 words): The article evaluates how an "epistemically insightful" approach to Informal Science Learning (ISL) outreach at Canterbury Christ Church University can impact students' attitudes, aspirations and perceptions of STEM.

Abstract (100 words): This article examines the impact that that an "epistemically insightful" approach to informal science learning (ISL) can have on students' attitudes, aspirations and perceptions of STEM at post-16 and HE. The article reports on interim findings from a mixed methods research and outreach project: "The Inspiring Minds" programme based in an Epistemic Insight-led approach at Canterbury Christ Church University, Kent, UK. The article reports on a sustained Saturday activity programme with 14-15 year-olds and residential summer schools with 15-17 year-olds designed to create confident scholars who can engage with difficult philosophical questions raised by current technological advances.

Introduction

An epistemically insightful approach to learning is one that supports students to recognise and investigate the links between curriculum subjects and develop their understanding of how knowledge is formed. This is about moving beyond topic-based work (that highlights the content taught within curriculum subjects) to developing students' understanding of the methods, questions and norms of thought of disciplines and the interaction between disciplines.

We report on an Informal Learning Intervention for teenagers that was developed to address common misperceptions about the nature of science and also barriers to engagement with STEM. As such the two aims of this project are firstly that it supports a widening participation agenda and secondly to test whether sustained engagement with big philosophical questions around science and technology would impact upon students' understanding of the nature of knowledge – and in particular, students' understanding of the power and limitations of scientific knowledge.

The "Inspiring Minds" project consists of three programmes "Inspiring Minds: ISL (Informal Science Learning)" a sustained Saturday activity programme; "Inspiring Minds: Summer Schools" 3 day STEM focused residential; and "Inspiring Minds: Roadshow" 60-90min in-school sessions covering the STEM Big Question content delivery from the ISL programme. This article presents data collected at the Saturday programme and Summer Schools to focus the discussion of the pedagogical approach.

The workshops introduce students to big philosophical questions and Real-world Problems. Exploring these questions and problems enables students to develop their understanding of the distinctiveness of science, and the importance of framing smaller questions that can be answered by science – in order to inform their thinking about the big philosophical question. Students are encouraged to reflect on the breadth of scientific enquiry by carrying out first-hand investigations and by researching secondary sources of data – to reflect on their own assumptions about the nature of science.

Analysis of the data indicates that students' engagement with the nature and distinctiveness of science and other disciplines across the Inspiring Minds programmes enabled them to develop their understanding of the nature of science. Preliminary results indicate a positive shift in their understanding of science in society as well as their reported future engagement with STEM. We argue that, based on this ongoing work and existing research, the use of Big Questions and Real World Problems can engage students widely and in particular, those in currently under-represented groups. In addition, this study suggests that an epistemically insightful approach to STEM can effectively teach assessable and transferable curriculum objectives relating to the nature of knowledge. In this way the project fulfils an aim to address a gap in provision currently whereby many schools neglect disciplinary knowledge in order to focus on content (substantive) knowledge.

Context

The STEM Widening Participation Landscape

Term & Acronym	Definition
Informal Science Learning (ISL)	ISL refers science (and science-based) activities that happen in out of school settings (including after school clubs, museums, some university outreach activities, etc).
Kent and Medway Collaborative Outreach Programme (KaMCOP)	Under the Uni Connect programme (previously National Collaborative Outreach Programme - NCOP) KaMCOP is a group of universities and colleges that have come together to deliver targeted outreach across Kent and Medway in England.
School and College Engagement (SCE) Team	The School and College Engagement Team is responsible for all central outreach work of the university. It works with it works directly with students, parents, teachers and schools and colleges supporting work raising aspirations and attainments.
Uni Connect	The Uni Connect programme (previously NCOP) is part of the government's 'Office for Students' in England. It oversees collaborative programmes that aim to reduce the gap in HE participation between the most and least represented groups. As well as contributing to a stronger evidence base around 'what works'. Uni Connect and KaMCOP both work with "target wards" which are postcodes that have low participation in HE and lower participation than expected considering prior attainment. Many of the postcode areas also meet other indices of deprivation.

Table 1 Key Terminology and Acronyms Associated with UK STEM Widening Participation

There is a well-documented difficulty in encouraging students from diverse socio-economic backgrounds, and women particularly, to pursue STEM careers (Grove, 2013; ASPIRES, 2013). As part of the Office for Students (OfS) Uni Connect programme (previously NCOP), Canterbury Christ Church University has developed STEM outreach programmes underpinned by an epistemically insightful curriculum and themed around Big Questions. The collaboration involves the School and College Engagement (SCE) team and the LASAR (Learning about Science and Religion) team within the Faculty of Education.

The Inspiring Minds programme aims to encourage progression in to HE and it investigates the impact of workshops on young people's perceptions, attitudes and aspirations around STEM. Whilst, current research shows mixed findings on the impact of STEM enhancement activities on improving the likelihood of under-represented groups continuing to study STEM subjects (Banerjee, 2017), there is some evidence to suggest that conveying the relevance of science in carefully selected contexts can help foster students' interest in and perceived utility of science, which may then encourage science career aspirations (Sheldrake, 2017).

The programme also aims to enable young people to become confident scholars who can engage with philosophical and multidisciplinary questions. Here, the underpinning concept is that the use of big philosophical questions, can enable students to develop their understanding of the distinctiveness of science. Students also learn that framing smaller questions which can be investigated scientifically can inform their thinking about the big philosophical question. The project work and academic sessions encourage students to reflect on the nature of scientific knowledge and enquiry and examine their own positions about the power and limitations of science alongside those of their peers and workshop facilitators.

Appreciating the power and limitations of science is an aspect of epistemic insight that is specified in Key Stage 4 (age 13-16) science curriculum. Previous research has established that we cannot expect students to appreciate the nature of science solely on the basis of their experiences of 'doing' science alone – and that their experiences need to be supported by explicit teaching on the nature of science (Craven, 2002; Schwartz et al. 2004; Seeker 2005). Billingsley and Nassaji (2019) and Allchin (2013) are advocates for the transformative power of engaging students in a discussion about the nature of knowledge in the context of a case study or real world problem (e.g. what is the purpose of looking for knowledge in this context and what knowledge can we obtain that might help).

The motivation for this innovative approach stems from research by Billingsley (2017) which examined the impact of entrenched curriculum compartmentalisation on students' perceptions of science (i.e. their epistemic insight into the nature of science) and in turn how pedagogy influences their expectations about the relevance of science for them. The research highlighted that entrenched curriculum compartmentalisation alongside other pressures and barriers in schools systematically dampens students' expressed curiosity about Big Questions. It also found that entrenched compartmentalisation narrows the contexts for learning about the nature of knowledge to questions that are asked within each discipline – rather than also including questions like Big Questions that reach across them. When this is considered in connection with research on the importance of science capital (Wellcome, 2017) it creates a case that students from low participation backgrounds are unlikely to have opportunities to work with contexts they find engaging to develop their understanding of the strengths and limitations of science.

To respond to these findings, Billingsley et al. (2018) created a framework to explain how students' epistemic insight can be developed using a range of enquiry-based approaches – where some enquiries sit within disciplines and other bridge across them. In Inspiring Minds, we focus on working with Big Questions and Real-world Problems. As Billingsley and Nassaji (2019) explain, the advantage with teaching about the nature of knowledge in the contexts of Real-world Problems is that the choice of problem and contexts can be styled around student interests. It has been established that in order for students to progress with STEM post-16 they need to see that they have a place within science and that it is "for them" (Archer, L., DeWitt, J., & King, H.; 2018).

Epistemic Insight and ISL Curriculum Rationale

The Inspiring Minds Programmes posed two key challenges, firstly to present ISL in a way that is meaningful and engaging for the students; secondly, and arguably more pressing, is that before students can consider participating in STEM in HE they must first be able to see themselves as confident scholars with the critical thinking skills and epistemic insight to engage with and contribute to the discussion. The programme aims are set out within the methodology.

Development of an ISL curriculum raises the question of whether to focus on knowledge application or knowledge generation. Knowledge application refers to students being able to use knowledge they already have, whereas knowledge generation refers to students creating new knowledge (with the newness being relative to the student). In an informal setting with students from multiple schools and ability range in each session, the curriculum cannot be based on assumed prior scientific knowledge, this can lead to ISL focusing on knowledge generation. However, the epistemic insight approach uses multidisciplinary big questions, enabling students to engage with both tasks. Students can access the STEM activities through application of their existing knowledge in science and (as importantly) other disciplines. This aims to ensure that students aren't faced with a starting point of feeling unable to undertake STEM research because they have already disengaged from or had a poor experience with STEM at school. Therefore, in explicitly challenging misperceptions about the nature of science and the relationship between science and other disciplines, students are able to apply their existing knowledge and engage with knowledge generation.

In addition, the curriculum for Inspiring Minds was designed to offer an alternative to the close-ended epistemic processes modelled within current formal science learning. Close-ended processes require students to find a single "right" answer to the question/project, this model can lead to students feeling under pressure with a fear of "getting it wrong" that can negatively impact their engagement (Allchin, 2013). The use of Big Questions, and student-led investigation enables students to contribute to the STEM debate and facilitates their entry at different levels by enabling them to either develop their own smaller close-ended processes/questions or to continue to engage at an open-process level where the output draws together approaches or responses from a range of disciplines (see Table 3 for ISL curriculum summary).

Session	Session Aims
1. Who Am I Online?	Examines the relationship between identity, self-representation and the impact of social media. Examines social & psychological models of identity. **Epistemic Insight outcome**: Different disciplines have different preferred methods, questions and norms of thought.
2. Does Siri "Just" Listen? Siri??	Examines the language used to discuss technology and the boundaries between defining human and non-human personhood. **Epistemic Insight outcome**: There are some questions that science hasn't yet and may never be able to answer. **Epistemic Insight outcome**: today we ask big questions about human personhood and the nature of reality that bridge science and religion.
3. What's the Universe Really Made of?	Examines how our understanding of the nature of reality is informed by maths as a language, and everything we know about living and non-living things is informed by this language. **Epistemic Insight outcome**: Science informs our thinking about every aspect of our lives
4. Is Seeing Believing?	Examines how senses, thinking and memory can be manipulated and where we place our trust. Examines illusions caused biological limitations as well as those with roots in psychology/ inference. **Epistemic Insight outcome**: There are some questions that science hasn't yet and may never be able to answer.
5. Showcase Preparation	Final preparation of CREST Award projects, planning for Showcase presentations
6. Showcase	Students present their CREST project and wider Inspiring Minds work to an audience of academics, parents/carers

Table 2 Summary of Inspiring Minds Academic Sessions. Sessions 1-4 provided 90-minute content delivery via interactive workshop followed by 90-minute CREST research session. Session 5 was a three-hour CREST research session.

Methodology

This article reports interim findings of a sequential mixed methods design. The quantitative data was gathered through repeated measures questionnaires collected at the beginning and at the end of activities. Following completion of the programme, semi-structured interviews were undertaken with a subset of cohort one Inspiring Minds: ISL students to develop a richer understanding of the impact of the curriculum on their perceptions of STEM. The survey was piloted with the first cohort of Inspiring Minds: ISL and, subsequently, additional survey questions were included for Cohort 2 and the Summer Schools to evaluate attitudes towards future participation in STEM, self-concept in STEM and the perceived societal importance of STEM. These questions were derived from the 'attitudes towards science' measures developed by Barmby et. al. (2008) but were modified to ask about STEM (not only science). Themes from the quantitative (survey) analysis and from the qualitative survey and interview data were synthesised and inferences were drawn to make conclusions. The success of the programmes was measured against the following objectives:

1. Students' to be more positive about their possible future education and career opportunities in STEM.
2. Students to self-report more positive perceptions of their academic aspirations, behavioural intentions (what they intend to do in the future), self-efficacy and attitudes towards STEM.
3. Students to develop their knowledge of HE, subject specific knowledge (STEM) and technical skills
4. Students' to develop more positive perceptions of the nature of STEM by exploring it in real world contexts and multidisciplinary arenas (particularly examined via student interviews).

Repeated measures were used (taken at baseline (pre-intervention) and follow-up (post-intervention)) to assess attitudinal change as short-term outcomes for a range of themes (Table 5), including measures for self-concept (an affective or emotional judgement related to a topic) and self-efficacy (a judgement about 'one's ability to organise and execute the necessary actions to attain a goal') (Beier *et. al.,* 2008). The post-intervention survey additionally asked for feedback on the perceived benefits of the project and included open questions to elicit qualitative feedback from the students on the impact of the sessions. Qualitative data from the questionnaire were thematically analysed, guided by the 'benefits to ISL' themes from Wellcome Trust (2017) research. Paired sample statistics (Paired t-test) were used to assess changes in measures over time and analysed using SPSS.

In addition to repeat surveys Interviews were conducted with 17 students from Cohort 1 of Inspiring Minds: ISL. The cohort was chosen due to the school's willingness to engage with the research and therefore, students' perception of science learning in school may be indicative of a local rather than generalisable trend. However, the students represent a range of formal science engagement and academic attainment and their attitudes are comparable to large scale findings from previous research undertaken by the LASAR (Learning about Science and Religion) team.

The key organising member of staff was also interviewed during this period, and a Deputy Headteacher was interviewed at the start of the following academic year. The qualitative data was thematically analysed with extracts used to highlight the emergent themes. The interviews were undertaken to develop a greater understanding of the educational impact of participating in Big Question led ISL to engage students.

Dependent Variable	Statements
Educational aspirations	I am motivated to do well in my studies
	I am confident I could get the grades I need for further study
	I am confident I could gain a place on a course of my choice if I wanted to
Self-concept in STEM	I find STEM subjects difficult*
	I am just not good at STEM subjects*
	I get good marks in STEM subjects
	I learn STEM subjects quickly
Future Participation in STEM	I would like to study more STEM subjects in the future
	I would like to study STEM at university
	I would like to have a STEM related job
Importance of STEM in society	STEM is important for society
	STEM make our lives easier and more comfortable
	The benefits of science and technology are greater than the harmful effects
	There are many exciting things happening in science and technology
Future Intentions	How likely are you to apply to higher education in the future?
Perceptions of HE	It is for people like me
	I would fit in well with others
	I have the academic ability to succeed
	I could cope with the level of study required
Self-efficacy	If I study hard, I will get better marks
	I feel that I have a number of good qualities
	I am able to do things as well as most other people
	Setbacks do not discourage me
	I am a hard worker
	I finish whatever I begin
	I feel good about myself

Table 3 Repeated Measures Survey Questions (these results were reverse coded during analysis. This means that when analysed the score for each statement is reversed so that a high score on a negatively worded statement "I find STEM subjects difficult" means the same as a high score for a positively worded statement "I learn STEM subjects quickly". This enables scores to be averaged or combined to form a composite measure)*

Participation

Participating schools were selected through an open invitation to school across Kent and Medway, working with students meeting the Uni Connect targeting criteria. Places were offered on a first come basis to school able to recruit sufficient students (ISL cohorts typically serve three schools with a roughly even split across numbers). Students were recruited directly by the schools with some schools choosing to identify students were perceived to particularly benefit academically or socially from taking part. Across the Inspiring Minds programmes students were from fifteen schools throughout Kent and Medway.

Within the ISL cohorts discussed here, participation incentives, appeared to be a driver for initial involvement although engagement with the project work often becomes the motivating factor during the programme. The nature of incentivisation is discussed within the interim report, with ongoing work being undertaken to establish the particular mechanism that engages students currently disaffected.

These data report on 212 individual young people who were registered on the ISL activities with majority (140) taking part in Inspiring Minds: ISL (Table 4). Fourteen students completed both Inspiring Minds and a Summer School (leading to the registered total being 226). Overall, 94% were known to be from KaMCOP wards and 57% were female. The ratio of females was highest for the second cohort of Inspiring Minds (80%) and for the mixed summer school (87%). 95% of students were in Year 10 (aged 14-15). The remaining students were in year 9 (14 years old) and year 11 (16 years old). The interview data focus on the development and responses to the Inspiring Minds: ISL Cohort 1.

Cohort	Registered Participants	Completed Baseline surveys	Completed Follow-up surveys	Matched surveys
Inspiring Minds Cohort 1 (Jan 2018)	68	50	42	35
Summer School July 2018 (mixed)	43	40	40	34
Summer School July 2018 (boys)	43	40	36	35
Inspiring Minds Cohort 2 (Sept 2018)	72	56	51	43
TOTALS	226	186	169	146

Table 4 Summary of survey data collected

Responses were matched for participants completing both the baseline and the follow-up surveys (Table 4). The number of matched surveys was lower than the total number of participants and the mismatch was due to either: students not consenting to share their data; participants missing the first or last session when the surveys were completed; or missing (or incomplete) details such that an accurate match could not be made. Survey data (unless noted) refers to the combined data from ISL and Summer School programmes.

Results & Discussion

Baseline Attitude Measures

Baseline attitudes to STEM were collected on the Inspiring Minds cohort 2 and at the two Summer Schools. The results showed (Figure 1) that this sample of students largely responded neutrally to the statements measuring self-concept in STEM, future participation in STEM and the importance of STEM in society. The highest *level of* agreement was with the statement *"*there are many exciting things happening in science and technology*"* (56% agreed). The highest level of disagreement *at the baseline* was with the statement *"*I find STEM subjects *difficult"* where only 24% agreed/strongly agreed.

We were interested in benchmarking the results to understand whether the attitudes of the participants towards STEM were in-line with previous studies in the area. To contrast the results with those of Barmby et. al. (2008), the responses shown in Figure 1 were first numerically coded (where 1 = strongly disagree and 5 = strongly agree) and averaged for each of the three multi-item attitudinal constructs (Self-concept in STEM, Importance of STEM in Society and Future Participation in STEM). The results showed the average values for future participation in STEM were noticeably higher when compared with Barmby et. al. (2008), also accounting for the downward trend over year groups. However the results for the importance of STEM in society and self-concept in STEM were more in-line with the anticipated downward trend observable over subsequent year groups (Table 7 and Figure 2).

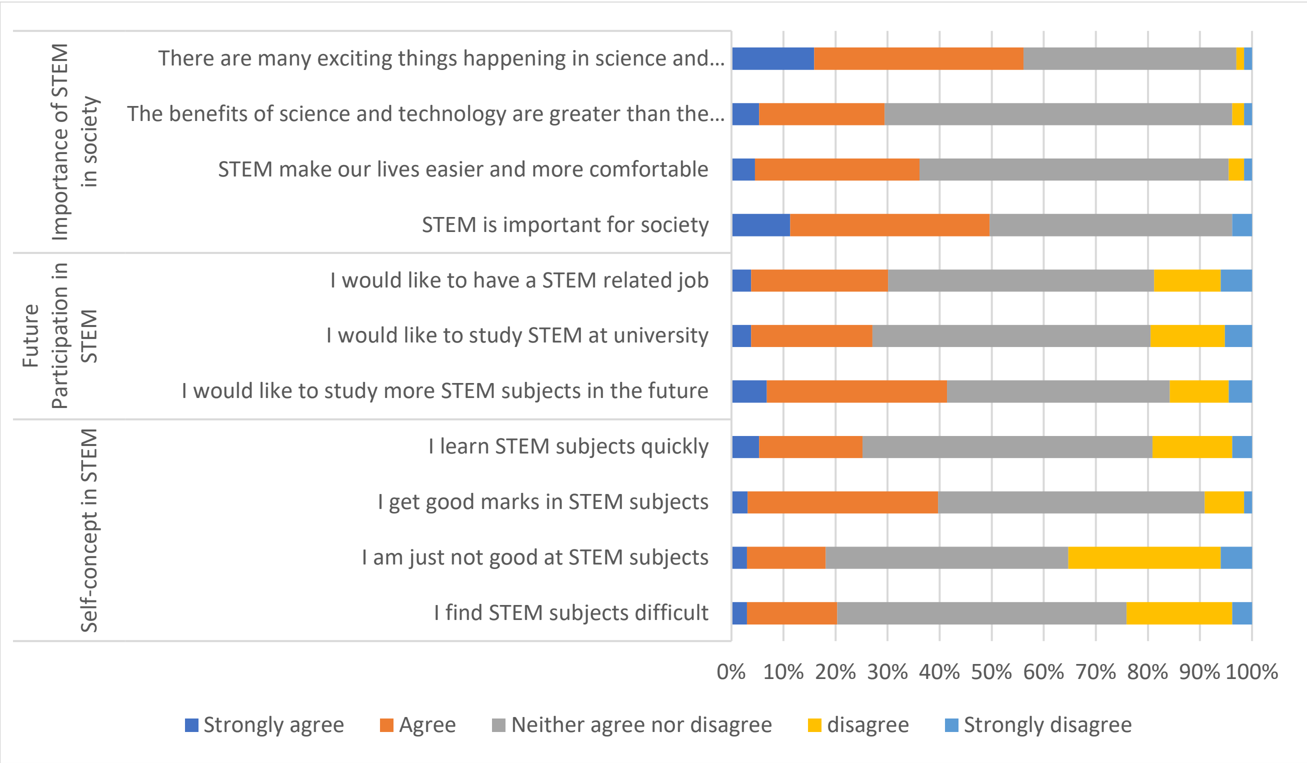

Figure 1 Summary of next step responses

	Barmby *et. al.* (2008)			**KaMCOP ISL**
	Yr7	**Yr8**	**Y9**	**Yr10**
Importance of STEM in society	3.65	3.45	3.35	3.16
Future participation in STEM	2.60	2.55	2.45	3.14
Self-concept in STEM	3.70	3.60	3.60	3.46

Table 5 Summary of averaged responses to the attitudes to STEM question subsets (Note: The Barmby study asked about attitudes towards science. Results in Table 5 are contrast ?? for illustrative purposes only)

Distance travelled – changes in attitudes

The programmes were designed to positively impact students' attitudes towards STEM. The baseline and post-activity surveys were compared for each participant, and the pattern and magnitude of change were analysed for the sample to understand the overall trends. The magnitude of change in the repeated measures is illustrated in Figure 2 for a selection of the dependent variables where a positive score represents a positive shift in the attitudinal measure (e.g. a change from 'Agree' to 'Strongly Agree' = 1).

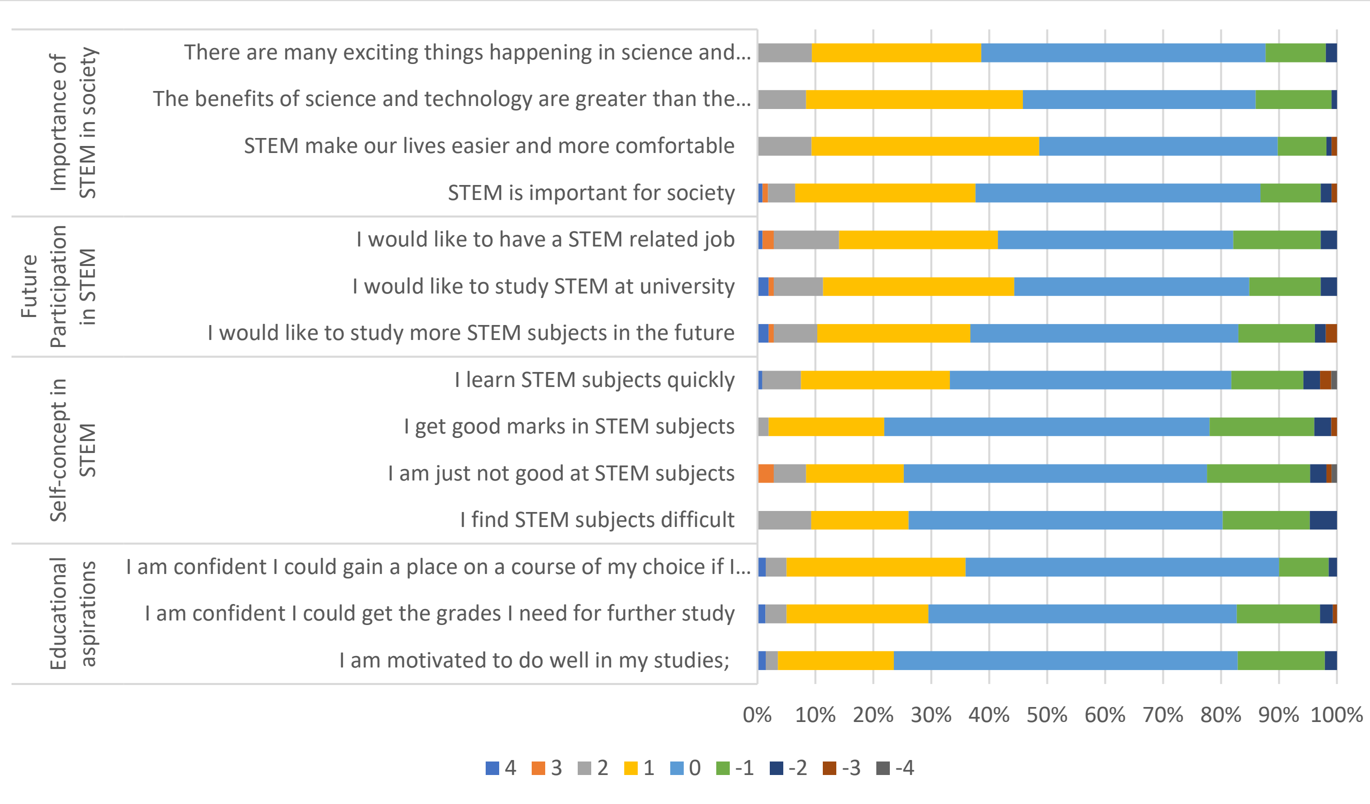

Figure 2 Summary of change in scores for matched individual responses

Effect size calculated using Cohen's d = $(\text{Mean}_2 - \text{Mean}_1)/\sqrt{((\text{St.Dev}_1^2 + \text{St.Dev}_2^2)/2)}$: 0.2 to 0.5 = small effect, 0.5 to 0.8 = medium effect, 0.8 and higher = large effect.

The p values indicated that there was positive differences in results over time, that these were not likely to be due to random chance and that the magnitude of the differences were small (as would be expected with attitudinal measures).

Using paired sample statistics, the results showed the most statistically significant change (where p is the probability that the difference is random and a small value, typically less than 0.05, indicates evidence for the difference being due to the test) in all the statements within 'Importance of STEM in Society' ($p \leq 0.001$), although all had a small effect size ($d \leq 0.36$) – where the effect size indicates the magnitude of the results. Students also displayed a statistically significant shift in attitudes across the 'Future Participation in STEM' statements ($p \leq 0.008$) again with small effect sizes ($d \leq 0.28$).

Participants displayed a significant shift in two of the statements related to Educational aspiration ('I am confident I could get the grades I need….' $p \leq 0.001$ and 'I am confident I could gain a place on a course of my choice if I wanted to' $p \leq 0.001$), with small effect sizes ($d \leq 0.27$). With regard to the dependent variable 'perceptions of HE' , a significant, positive change in attitudes was seen across all four statements ($p \leq 0.002$). The effect sizes were small (≤ 0.32) for the statements *'it is for people like me'* and *'I would fit in well with others*'. The likelihood of students applying to Higher education in the future also displayed a positive shift ($p = 0.052$, $d = 0.12$).

Whilst the change in scores were not significant for all four 'self-concept in STEM' statements, there was a significant positive change in the responses for five of the eight self-efficacy statements. The effect size was largest for the statement '*setbacks do not discourage me'* (d=0.21).

Comparing year groups 7, 8 & 9 (aged 11-13) from a cohort of 932 students across five schools and 3 English regions, Barmby et, al. (2008) found pupils' attitudes towards science declined as they progressed through secondary school, and this decline was more pronounced for female pupils. Whilst the results are not directly comparable (due to both methodological and contextual differences), the results from Inspiring Minds (combined for ISL and Summer School) showed perceptions of the importance of STEM in society and possible future participation in STEM were enhanced on completion of the outreach activities (Figure 2). The results for 'self-concept in STEM' were in line at the baseline and were relatively unchanged on completion of the outreach activities.

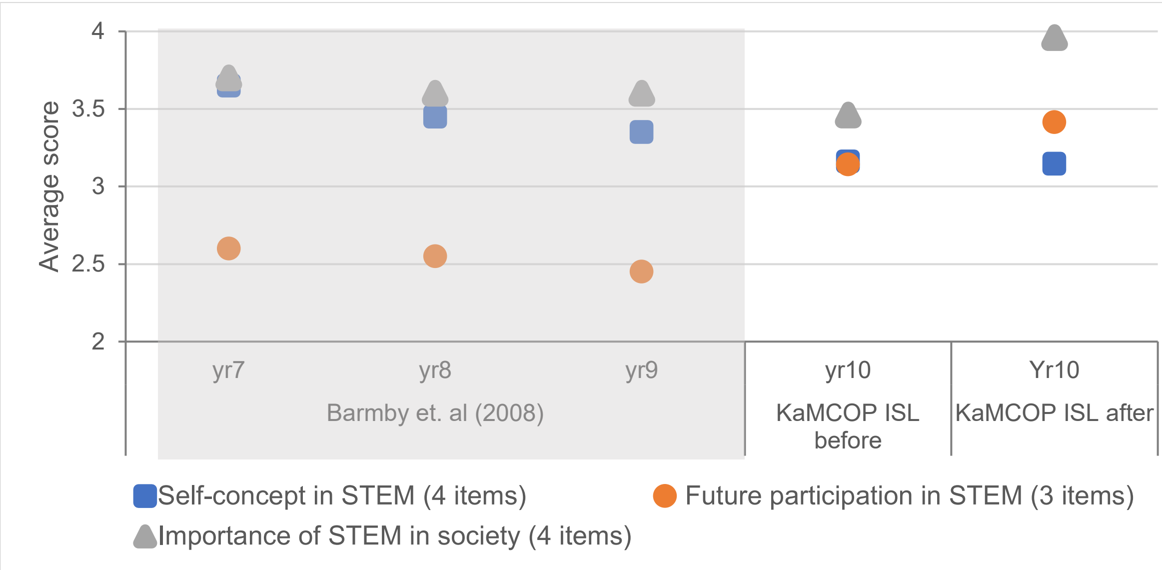

Figure 3 Inspiring Minds: ISL – Changing attitudes to STEM

The variable 'perceptions of HE' consisted of four statements (Table 3) and there was a positive change in the responses to all of these statements. The effect sizes were small (d ≤ 0.35) for the statements *'it is for people like me'* and *'I would fit in well with others'*.

In summary, the data showed predominantly positive changes in the young peoples' attitudes that corresponded with their participation in the activities as anticipated. Moreover, the changes in self-reported attitudinal measures were consistent across a number of cohorts during different semesters and different academic years. The general replication of positive trends in attitude change over different groups of young people measured at different times suggests a positive association with the interventions.

The single time-point feedback gathered via Likert-type statements (on completion of the intervention) indicated that the majority of the students felt they benefitted from the informal STEM-based learning (Figure 3), for example 79% agreed that they enjoyed taking part. The responses indicated that 77% of the young people taking part said they had been motivated to study STEM by the ambassadors (77% agreed) while 65% said they had been motivated by the academics. Feedback gathered for Inspiring Minds indicated that taking part had helped students feel more supportive about the benefits of science and technology in society (80% agreed). Whilst 60% agreed that taking part had helped them feel more confident in classroom discussions.

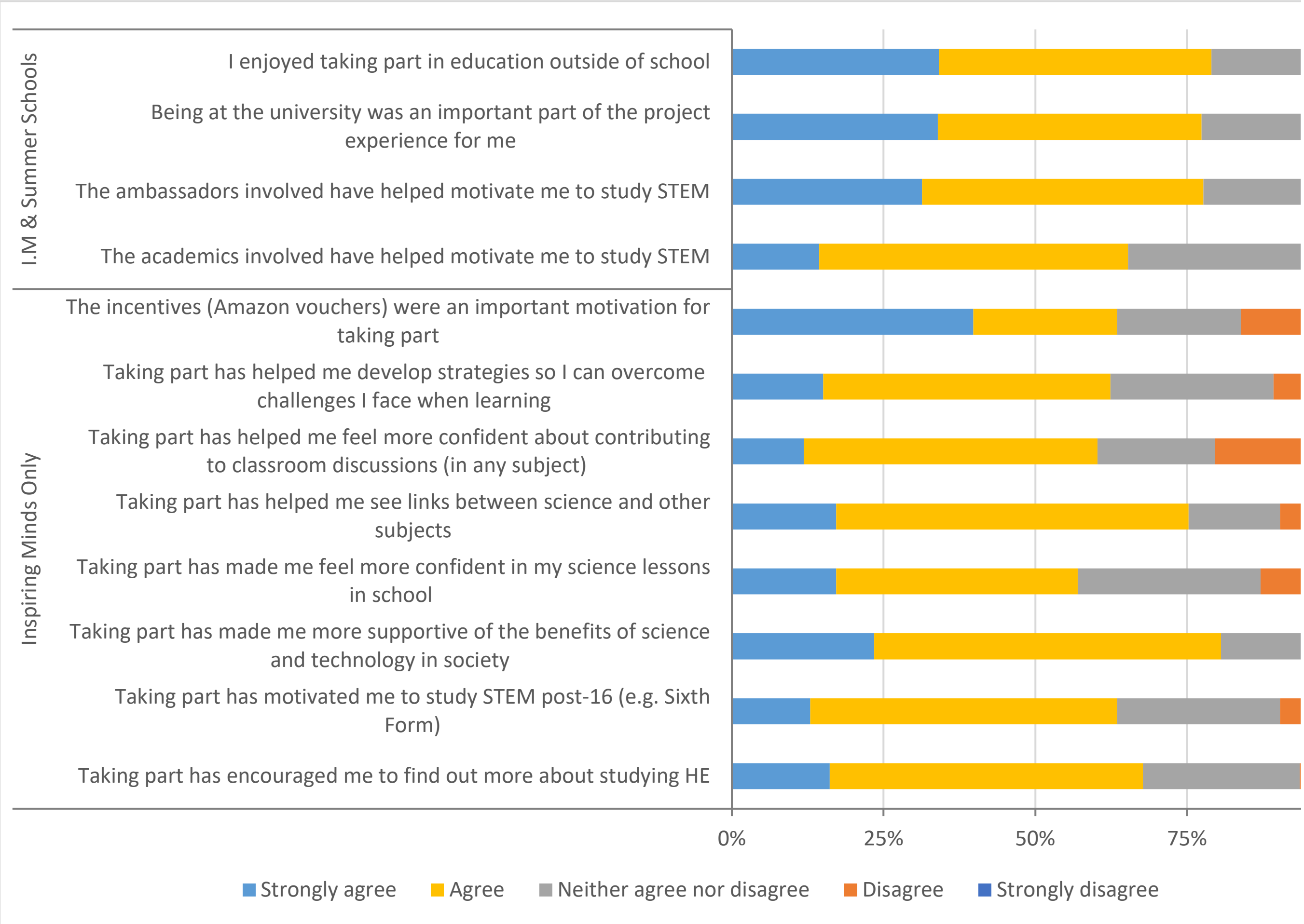

Figure 4 Feedback on the benefits of taking part in informal STEM learning

Initial Interview Analysis

Four key themes arose from the student interview data (a) students engaged with the opportunity to undertake independent learning; (b) students' engagement with science through the lens of big philosophical questions; (c) how the style of the informal science education differed substantially from "school science" and (d) the impact the programme had on their interest in HE.

Within the interviews from Cohort 1 repeated themes in discussion of the value of engaging with the project centred around opportunities to be in charge of their learning; undertaking a research project and/or the acquisition of transferrable skills. These benefits were also highlighted by Allchin (2013) as significant features in reforming science education. Indeed, some students viewed the opportunity for independent learning as the most valuable outcome of engaging with the project and noted that it had impacted on their learning in school as they had used the skills to complete (non-STEM) homework. Additionally, the qualitative findings echoed those of the Wellcome interview study (2017) with 'Understanding the broader context of science in society' being a key emergent theme. For example: "*This helped me better understand the world around me and current technology*" and "*It shows how much the earth is in danger and that we need to do things to help the environment*".

This theme is of particular interest as it is closely tied to the rationale of an epistemic insight-led pedagogy. It is notable that there was there was a strong recognition by students in Cohort 1 (and in informal discussions with Cohort 2 students) of a move in their understanding of the nature of science from the narrow concept-led experience at school to the real world opportunities in STEM beyond the classroom. Students spoke of having gained an understanding of how much their daily lives are "*all linked with science"*; or that that science "*is something better than just sitting in a classroom learning, because it had a bigger impact*", with this wider understanding of science also fuelling some students' aspirations to explore science beyond school. Independent learning and/or freedom were mentioned explicitly in nine of the interviews. Students frequently commented on the achievement or enjoyment of having the freedom to "*do our own research and find out our own stuff*" which was often placed in comparison to school science that is "*just copying out of a textbook*" or "*exam style questions you've gotta do it like this, this is the answer, this is the wrong answer, you don't really get to have your own opinion*" with one student going 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*". For some students the lack of a single answer or method was one of the most challenging aspects of the programme and it was this change in their understanding that there can be multiple perspectives or answers which they took through to their learning in school. The opportunity for students to engage in independent learning was also drawn out in the staff interviews as one of the anticipated gains for students "*the confidence to criticise and analyse in the exam*". With the Deputy Headteacher noting that the draw to participate was "*for introducing students to higher level thinking and empowering them to be able to access material they wouldn't have normally thought they could*".

Students were asked about their experience of engaging with big philosophical questions in both the workshops and as part of their CREST award and the response from the majority of students was an overwhelming enthusiasm for investigating science in this way (in comparison to their experience of school science). 11 students specifically referred to a preference for exploring science in a philosophical and multidisciplinary way and many felt they would be more engaged in science if it was taught in this manner. "*[science] is very different [at Inspiring Minds] like you get more opportunities and experiences like to explore different aspects of it [science]".* Students reported greater understanding of the relevance of science as a result of seeing its relevance to real world and multidisciplinary contexts and being challenged by the diversity beyond physical sciences: "*because this has proved what science actually is, because in school that's what I know science as but then this expanded on what science is and that I enjoyed that part*".

Closely linked to students' engagement with big questions was the comparison with the recipe investigations and engineered narrowing of what is amenable to science through school teaching. Particularly notable were the students who self-defined as "not science" students but who enjoyed the science experience at Inspiring Minds. "*I found it a lot better than like school 'cause you can open up so much more different things with it […] like I'd have to maybe bring some maths in to it for some reasons or like some English just to like look at it from a different perspective*". Many students perceived school science as being about "facts not questions" and that the content/concept focused science curriculum didn't allow them enough opportunity to gain a deeper understanding about understanding how things work "*I prefer to do more looking into how things work, but that's the same with science I'm just not very good at science*". The interviews made use of students' survey responses in order to generate a deeper understanding off the impact of the pedagogy on their engagement with and interest in STEM (at school and post-16). Whilst the surveys had a broader focus the interviews prioritised in depth conversations with the students about the impact of the ISL curriculum on their engagement and used the survey responses to initiate a richer conversation around motivation and attitudinal shift.

Conclusion

The findings of this study indicate that students' engagement with the nature and distinctiveness of science and other disciplines across the Inspiring Minds programmes enabled them to develop their understanding of the nature of science. Preliminary results indicate a positive shift in their understanding of science in society as well as their reported future engagement with STEM.

The majority of interviewed students self-described as disengaged from science within the formal school setting yet expressed motivation and engagement with STEM in real world and multidisciplinary arenas. The findings from the interviews, triangulated with the survey results, show a positive association between taking part in the programmes and development of more positive attitudes towards the benefits of science and stronger inclinations to participate more in STEM in the future. Respondents expressed disappointment/frustration that they're "*still always doing this kind of science [school science]*" and "*that's not what we do [in science] in schoo*l", the initial research highlights the importance of sustained STEM/ISL outreach underpinned by an epistemic insight pedagogy.

If Big Questions do indeed act as hooks for student engagement in STEM (and HE), then how do we offer students a genuine opportunity to develop their understanding of the nature of science (and STEM related careers) that captures those not being served by the current curriculum delivery?

We argue that, based on this ongoing work and existing research, the use of Big Questions and Real-world Problems can engage students widely and in particular, those in unre-represented groups. In addition, this study suggests that an epistemically insightful approach to STEM can effectively teach assessable and transferable curriculum objectives relating to the nature of knowledge. In this way the project fulfils an aim to address a gap in provision currently whereby many schools neglect disciplinary knowledge in order to focus on content (substantive) knowledge.

The importance and impact of the project has been recognised by the inclusion of Inspiring Minds (both ISL and summer schools) in the TASO (Transforming Access and Student Outcomes in Higher Education) Evidence Review (Robinson & Salvestrini, 2020). As well as forming part of NEON's (National Education Opportunities Network) Innovation Series which will report to the DfE on how we can improve the engagement of white working-class boys in HE. Inspiring Minds is one of only nine outreach projects, and the only STEM focused project involved.

There are also links to make with other aspects of STEM Education: findings by the Higher Education Academy (HEA, 2015) and the Royal Academy of Engineering (RAE, 2014) draw on the importance of multidisciplinary thinking for STEM careers. The engineering habits of minds identified by the RAE, are able to be developed and identified during Big Question ISL and develop students understanding of CDIO (Conceive, Design, Implement and Operate) approach to engineering education. The HEA report identifies key pedagogical principals that underpin high-impact student engaged learning within HE such as 'real world mapping of ideas', students being guided to independent enquiry and STEM learning placed in a meaningful context. What this speaks to is the need to continue to develop methods and opportunities, underpinned by ongoing research, to increase the sustained ISL and develop ways to bridge the informal outreach experience and the formal experience within schools.

Through further workshops and research we hope that this and similar programmes alongside work with teachers to develop students' epistemic insight within the classroom will support students who are traditionally disengaged with STEM to re-engage through a richer understanding of the nature of science in real world contexts.

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