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Levelling the playing field: lessons from sport on re-framing science engagement as a benefit to the individual

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Abstract

The workforces of the Science, Technology, Engineering & Mathematics (STEM) industries suffer from skills gaps and lack diversity. Science engagement activities often try to solve these problems through targeting audiences under-represented in the STEM workforces. There is limited data, however, to suggest that these engagement efforts are successful in translating into more diverse workforces. We draw upon Unicef's 'Sport for Development' model and propose a new conceptual framework: 'Science Engagement for Good'. This frames science engagement activities around the benefits to individuals, families and communities, rather than the benefits to STEM industries, the economy or society at large.

Keywords Science and policy-making; Science communication: theory and models; Social inclusion

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Introduction

Science engagement (SE) in the UK is a broad term for a wide range of activities, interventions, experiences, programmes and initiatives which are broadly designed to engage people (publics) in a variety of ways with science as whole, or a scientific discipline, or scientific research. It is carried out by a range of providers and facilitators with different motivations, for a variety of purposes. The language used to describe it is also varied, and for this reason we have included an Appendix of common terms and how we have used them in this paper (Appendix A). Some providers are scientists and researchers who are themselves motivated to engage wider audiences with their research, some learned societies and third sector organisations have missions to raise awareness or engage publics with science generally or specific scientific disciplines. Science engagement activities may also be provided by tertiary education providers performing outreach to schools, or as part of programmes for widening-participation in education, or sometimes more expressly for recruitment purposes.

The range of activities and events which are encompassed by science engagement are wide and varied. Science engagement activities may include visits to arts or cultural centres or venues including science centres and museums, and locations for public engagement events may include outdoor spaces, libraries, social and public spaces such as community centres, as well as traditional venues such as theatres. Visiting a static museum exhibit could be considered as accessing a public engagement activity, as may attending screenings at STEM-themed film festivals. The science engagement landscape, particularly festivals and venue-based engagement has expanded rapidly over the past two decades with the UK now hosting at least 47 festivals and 66 venues which wholly or in part have STEM engagement content, exhibits or activities [BIG Stem Communicators Network, 2022; UK Science Festivals Network, 2022]. Although such experiences can be a good way to engage publics with science, they also tend to attract audiences who are white, affluent and already engaged with science [Jensen and Holliman, 2016; Kennedy, Jensen and Verbeke, 2018; Dawson, 2019]. Further, there is uncertainty over their long-term effectiveness as an engagement tool, and it has been argued that, "the legitimacy of public engagement does not just depend on its inputs, but also on its outputs" [Stilgoe, Lock and Wilsdon, 2014].

The most recent UK government report into public attitudes towards science suggests that this growth in the number and availability of engagement activities and venues has resulted in increased reach, with 72% of people reporting that they had taken part in at least once science-related activity in the past year, (most commonly visiting a nature reserve, zoo or science museum). Despite this, only 22% of people felt actively connected with science and another 1 in 5 feel actively disconnected from science ("science is 'not for me').

While in 2019 almost half of people agreed that scientists make a valuable contribution to society, (49%, compared to just 27% in 2005), the number of people who believe that science will make their lives easier has fallen to 74% (from 81% in 2014). Alongside this the number of people who believe it is important to know about science in their daily lives has dropped to 65% (down from 72%), and only 43% of people now believe that school science has any relevance to everyday life (down from 51%). The data also showed that, of this group, almost 40% were actively connected to other cultural activities, (most commonly sport, but also the arts), and suggests that these other cultural interests could be a conduit through which positive attitudes towards science might be engendered.

Despite the increases in science engagement activity across the UK therefore, we seem yet to demonstrate significant corresponding shifts in attitudes of the public towards science across the general population. In addition, there are further issues in both the science workforce and science engagement in terms of demographic reach, which are discussed later in this article.

Understanding current models of STEM engagement

Science engagement has a rich history that extends as far back as the Enlightenment and is carried on today by schools, colleges and universities, and by festivals, museums, science centres and venues such as the Royal Institution [James, 2000; Bensaude-Vincent and Blondel, 2008]. Discussions about the categorisation and typology of different forms of engagement are plentiful and manifold with no 'superior' or globally agreed definitions, but broadly it can be described in several ways; practical, theoretical and applied.

Over time there have been three broad 'waves' of science engagement each using different practical models for engagement although all three are still in use today [Hetland, 2014]. Historically the primary mode of science communication was the 'deficit' model, that is, an assumption that audiences were 'empty vessels' to be filled by facts and knowledge imparted by the scientist. Examples of deficit model engagement are talks or TV programmes, more likely to be described as science communication than engagement. Two subsequent models for science engagement evolved from this, with the first being a dialogic model, which recognised that engagement can generally be more effective as a two-way discussion between audiences and scientists or science communicators, (for example interactive museum exhibits, participatory theatre, science cafes) [Jensen and Holliman, 2016]. The more recent evolution of this model is for participatory engagement in which publics are not considered audiences, but participants in an interactive engagement in which science communicators and scientists and publics can learn from each other. Hetland describes the models as constituting a "multi-modal framework" for studying science and suggests that although dialogic and participatory forms of engagement are often seen as superior to the deficit and dissemination model, the models can "co-exist as policy instruments" and neither negate nor exclude the others.

Engagement with science is also sometimes categorised as 'Upstream, 'Midstream' and 'Downstream' public engagement: 'Upstream' refers to bigger discussions about values, ethics and debates about science and research *before* trajectories are set, 'Midstream' refers to public engagement between scientist and public at the level of the laboratory research, and 'Downstream' refers to the application and commercialisation of scientific research, and discussions about applied science [Wilsdon and Willis, 2004]

Other analyses of public engagements have described different forms of public engagement as a typologies which map to different political leanings, as a way of understanding how a lack of diversity in engagement may result in the conferring of a "middle class advantage" in relation to public services, health, land-planning and education. Although this work does not attempt to quantify the relative importance of these advantages it is vital to understand how political and social factors affect equity of access to science engagement if we wish to understand why those who are under-served and under-represented as engagement participants continue to be in the minority [Marks, 2013].

What is the purpose of Science Engagement?

There are myriad reasons why people and organisations choose to become involved in facilitating or providing public engagement activities, and why policy-involved organisations suggest scientists (and others) should become involved in public engagement. NESTA, a science endowment organisation based in the UK, published a report describing some of the reasons why researchers, innovators and those involved in innovation policy-making should practice science engagement. Reasons given include a) providing a broader base of voices and stories for policy or law-makers to engage with when making decisions that may affect the future, b) to encourage researchers to think about broader social, political and ethical issues than they might do by themselves, (and in acknowledgement that the socio-demographic make-up of scientists and researchers does not reflect whole populations), c) to improve research by increasing diversity, in the understanding that a great deal of work demonstrates that problems are better solved when we can draw on collective intelligence from groups with cognitive diversity, and d) to ensure the fair sharing of the benefits drawn from science, research and innovation [Saunders, 2018]. These points summarise benefits to society at large from the wider engagement of publics with science, but the paper does not mention specifically that science research is funded to a great degree by taxpayers in many countries. While the value of scientific research to the world is considered by scientists to be high, it is often poorly misunderstood by those without scientific training, despite being largely paid for through direct taxation. There is therefore an argument that nations are duty-bound to engage those citizens whose taxation funds research, and that such spending can be fairly justified; Sir Paul Nurse in his 2015 Review of the UK research Councils wrote; "For a national research endeavour to be successful there needs to be an effective dialogue and understanding between research scientists, politicians and the public, so that policies and strategies are in place to bring about research that benefits society, and that society will support. Without this engagement and societal endorsement, the research endeavour will ultimately stall or even fail,"[Nurse, 2015, p. 8]. Many public engagement professionals and social scientists therefore believe the focus should be on enabling segments of the general public to influence decisions about the development and application of science and technology knowledge generated within the institutes [Salmon, Priestley and Goven, 2017].

At the level of education providers and third sector organisations, the motivation for public engagement is often mission or policy based education based on ideals of social justice and widening participation in science. The term "widening-participation" has come from the formal education sector which has targets for engaging and recruiting a student workforce from a wide range of socio-economic backgrounds, focussing on demographics who are under-represented in tertiary education, such as those living with multiple disadvantages and people from ethnic minorities. There is a great deal of support available for such initiatives because it has been recognised that the STEM industries globally face a skills-shortage in the workforce, which is compounded by its own lack of diversity. A number of reports, detailed below, have reinforced the need to expand the skilled workforce and identified that only by increasing the diversity of the workforce can they achieve these aims. Making study choices that are STEM positive and entering into the STEM workforce is also associated with increased income and improvements in social mobility, so there are good social justice reasons for wanting to improve the diversity of the STEM workforce, however, for many organisations and businesses there is a more pressing economic imperative of ensuring continuation in their workforce, and the need for this is discussed in the next section.

Overall however, there is a lack of research examining why scientists should participate in science engagement activities, and the literature reveals many opinion pieces imploring scientists to become involved in engagement activities, rather than critically examining what scientists can learn and contribute from doing so [Salmon, Priestley and Goven, 2017]. Consequently, the purpose and critical reasoning behind science engagement activities tend to be under-researched, and while research findings often do not drive science engagement practice, neither do engagement activities tend to drive or inform research, although this is changing in some areas with new approaches to citizen science activities [Salmon, Priestley and Goven, 2017].

The STEM Workforce and its dependence on diversity

The value of the STEM workforce for the UK economy has been recognised in multiple reports. 18% of the UK's workforce is employed within the STEM sector and its economic significance cannot be underestimated [Institute for Manufacturing University of Cambridge, 2021]. Multiple reports including the Industrial Strategy [1993], the UK Research and Development Roadmap [2020] and the Build Back Better Plan for Growth [2021] have outlined the vital importance of having a workforce that is adequately skilled in STEM to meet the requirements of businesses, particularly in the wake of Brexit and the Covid-19 pandemic [Etherton, 1993; HM Government, 2020; HM Treasury, 2021]. Existing evidence demonstrates that there is a gap between the STEM skills needed in industry and those readily available from the UK workforce [National Audit Office, Comptroller and Auditor General, 2018]. This shortage of STEM skills within the workforce has economic consequences for businesses and is estimated to cost £1.5bn per year in the UK [STEM Learning, 2018]. Investment in developing a strong STEM workforce in order to develop the STEM sector is considered to be key to strengthening economic output of science [Etherton, 1993; British Science Association, 2020].

Research on the existing STEM workforce found that it is far less diverse than the wider workforce; 65% of the STEM workforce in the UK are white men, and the National Audit Office [National Audit Office, Comptroller and Auditor General, 2018] reports that whilst some progress has been made to make the STEM workforce more diverse, addressing the inequity of access to science engagement would help address some ongoing economic considerations within the STEM economy [National Audit Office, Comptroller and Auditor General, 2018; British Science Association, 2020]. In 2020, the UK Parliament's All Party Parliamentary Group (APPG) on Diversity and Inclusion on STEM produced a report on diversity and representation in STEM industries in the UK [British Science Association, 2020]. They found, "an overall lack of representation in the STEM sector of minoritised groups such as Black people, women, disabled people and those from the LGBTQ+ community". Disabled people of all ethnicities are underrepresented in the STEM workforce. The gap in representation between STEM workers and others is larger for disabled women than disabled men. [British Science Association, 2021]. Whilst a majority of non-STEM disabled workers are female (59%), only one-third (33%) of STEM disabled workers are female. The impact of sexual orientation on science engagement and uptake of STEM careers, for example, was not considered by the APPG however an earlier report from the IET identified that 28% of LGBTQ+ people would not consider a career in STEM due to perceived fear of discrimination within the sector [IET, 2008]. The report goes on to say that the STEM sector "cannot reach its full potential without greater equity in the workplace," noting that the inequity is both historic and systemic.

Internationally there have been drives in the last decade towards increasing the uptake of STEM subjects by school students and at undergraduate level. The STEM skills shortage in the UK is thought to result in around 43% of STEM vacancies being difficult to fill. Reasons for this (according to the UK Commission for

Employment and Skills) are applicants not having sufficient training or experience, and this is reported to impact heavily on the industrial and economic output of the nation [Vivian et al., 2016]. Some businesses with large UK bases, such as Siemens recognised the potential deleterious effect the skills gap may have on them and have taken action to address the issue, identifying science engagement as a strategic organisational priority in a 2015 report. Many STEM industry companies have similarly invested in science engagement events and activities in the hope of minimising the disruption that a future skills gap might bring to the business. While such investment is welcomed in general by the engagement community (notwithstanding ethical concerns by some engagement practitioners regarding funding from industry sectors, such as arms manufacturers, or fossil fuels industries), it continues to frame science engagement and increasing diversity as a necessity to benefit STEM industries and/or the economy, rather than the under-represented individual [Langley and Parkinson, 2009].

Factors associated with STEM choices and the intersection with diversity

While the economic and social justice pressures have seen an upswing in science engagement activities and experiences, the same lack of diversity that is reported in STEM industries is reflected in science engagement demographics. Although there is an assumption that increasing science engagement of young people is likely to result in an increased number of people making study and careers choices in STEM, this is not a given, and if the diversity issues in engagement are repeated within the STEM industries, then ultimately we will be unsuccessful in building a bigger (and by necessity more diverse) workforce. It is imperative therefore that we understand the causes of the lack of diversity in both engagement and in study choices and careers. The following sections explore factors that are known or thought to have a bearing on STEM engagement and choices and the relationship between these factors and diversity. Note that these sections do not constitute a systematic review of the evidence, but briefly explore this complex field to suggest where patterns emerge that might help us to understand the intersectional factors at play in STEM engagement and diversity.

Identity, capital and experience

The reasons leading to low uptake of science with certain demographics are complex, however, the concept of 'science capital' proposed by Archer has been useful in exploring how barriers to engagement with science can negatively influence the likelihood of individual's decisions to study a STEM subject or participate in a STEM career [Archer, Moote and Tomei, 2013; Archer, DeWitt, Osborne et al., 2013]. Archer's theory of 'science capital', elaborates on Bourdieu's theory of social reproduction, which defines 'capital' as "the legitimate, valuable, and exchangeable resources in a society that can generate forms of social advantage," [Archer, Dawson et al., 2015]. Archer defines science capital as "the sum of all the science-related knowledge, attitudes, experiences and resources that an individual builds up through their life. This includes what science they know about, what they think about science, the people they know who have an understanding of science, and the day-to-day engagement they have with science"[House of Commons, Science and Technology Committee, 2017]. Much of this research stems from 'Aspires', a longitudinal study with more than 40,000 participating young people who were followed from age 10 to age 19 [Archer, DeWitt, Osborne et al., 2013; Archer, Moote, Macleod et al., 2020]. Aspires is one of the largest and most significant pieces of research into young people's attitudes to STEM, and showed that children from families with higher levels of science capital tend to be from middle-class families, and these children are disproportionately more likely to pursue science post-16 [Archer, Moote and Tomei, 2013]. Conversely, children with lower levels of science capital are more likely to be Black, working class, and are less likely to study science post-16. These children may view science as being 'not for me' and are less likely to see science as a potential career [Archer and Moote, 2016]. Working class and minority ethnic students were more likely to experience greater teacher turnover than other students, and "gatekeeping" practices on subject choice were reported. This was most common in Physics with all but the highest achieving students discouraged from choosing it at A level and the Physics curriculum reported as being particularly off-putting [Archer, 2020; Archer, Moote and MacLeod, 2020].

Critically, Aspires identified that it was not poverty of aspiration, interest or attainment that prevented people from under-represented groups from progressing their studies, but other factors, some of which were identified decades ago, which instil science as being "not for me", and persist as barriers to access today. According to Archer "teachers' attitudes and behaviours, young people's experiences of school science, and the nature of the curriculum all play a part in reinforcing or undermining science aspirations and identities" and the extent to which individuals identify with science, affects their behaviours and choices [Archer, 2020].

The concept of "science identity" is part of the complex of values that create science capital and building a positive science identity is linked to higher science capital in individuals [Archer, Dewitt and Osborne, 2015; DeWitt and Archer, 2015; DeWitt, Archer and Mau, 2016].

This work has done a great deal to enhance our understanding of some of the factors which affect or determine individual's attitudes to science, which in turn influences their behaviours, particularly regarding study choices and subsequent career decisions, and also suggested that some (but not necessarily all) forms of science engagement and informal science learning experiences may help to build science capital, but also determined that these experiences were not the only things that would contribute to the level of science capital. Critically, the ability to change an individual's attitude to thinking that science "is for me" and to encourage activities and dialogue that explore and underpin the relevance of science to their everyday lives are equally if not more important than "fun" science experiences [TED, 2015].

Emily Dawson's important contributions to this field take phenomenological and ethnographical approaches to understanding the barriers to accessing informal science learning (ISL) faced by people who are minoritised by ethnicity [Dawson, 2014; Dawson, 2015; Dawson, 2018]. This work echoes and develops some of the seminal explorations to understanding barriers to accessibility to museums made by Marilyn Hood in the 1960s and 1970s. She observed that the codes and behaviours of visitors to museums represented the values of white middle class males, and that people who do not fit this demographic and may not learn these codes, they are exclusionary [Hood, 1983; Hood, 1991; Hood, 1993]. Dawson's work with UK-based ethnic minority community groups has shown that 50 years later many of the same issues are still at play with museums access still "grounded in expectations about visitors' scientific knowledge, language skills, and finances in ways that [are] problematic," arguing that "ISE practices reinforced participants pre-existing sense that museums and science centers [are] "not for us." Hood herself followed up her initial writings ten years after publication asking what had changed in a decade, and it is of note that Dawson's work 30 years on highlights that little has changed. [Hood, 1983; Hood, 1993; Borun and Chambers, 2000; Dawson, 2014; Archer and Moote, 2016]. One aspect uniting these works is the revelation that for many, science is considered "not for me" and is not considered or discussed as part of every-day life, suggesting that person-centred, individual-first approaches to science engagement may be a way forward that can help overcome the inequity witnessed in science and science engagement.

School attainment and socio-economic factors

The link between socio-economic disadvantage and school attainment has been addressed in several studies and recently by a systematic review by Banerjee which identified factors linking to underachievement in disadvantaged pupils [Banerjee, 2017]. Banerjee reports that remediation of the situation is imperative for five specific reasons including greater diversity leading to innovation in the STEM workforce, social justice, narrowing the socio-economic divide, allowing everyone to harness STEM skills for themselves and the protective effect of educational attainment on health. Factors involved in linking socio-economic disadvantage and attainment at school were many, including poor attitudes towards schooling and lower attainment across the board due to early cognitive developmental delays, and there is also a known "neighbourhood" effect in which behaviours (such as exhibiting or experiencing aggression and violence or other high-risk behaviours) negatively impact school experiences. Enriched schooling has been shown to mitigate some of the negative school experiences in the US [Hanson et al., 2011].

Parental involvement in education is also linked to attainment and was more predictive than social class or practical formal support, whereas socio-economic status, particularly of migrant communities, was negatively associated with attainment. Attitudes of schools and teachers played a role in attainment, with both perceived and structural discrimination being a factor for lower socio-economic status and minority ethnic groups. [Greenman, Bodovski and Reed, 2011; Archer, Dewitt and Osborne, 2015].

Beyond the UK, PISA is the OECD's programme for student assessment and measures 15-year-olds' ability to use their reading, mathematics and science knowledge and skills to meet real-life challenges. A large-scale study in "Dream Jobs? Teenagers' Career Aspirations and the Future of Work" [Mann, Denis et al., 2018] carried out an analysis of PISA data, the world's largest educational attainment database to look at the relationship between aspiration and achievement [Mann, Denis et al., 2018]. They found that young people from the least advantaged backgrounds who "performed well on science tests commonly expressed much lower career expectations than comparably performing peers from the most advantaged backgrounds" and were half as likely to express an aspiration to continue to tertiary education than their more affluent and advantaged peers.

The report suggests that, other than a small number of countries in which this may be a result of vocational training frameworks, "the phenomenon speaks to barriers preventing disadvantaged youth from meeting their educational potential".

Although a significant body of research governing attitudes to science and STEM and attainment at school, and reasons for failure to attain in the STEM subjects, there is currently little in the literature, (other than a link between the existence of STEM clubs and study choices), to link the importance or otherwise of school attainment on equity of access to informal science learning. The work that does exist however, may again point towards structural issues impacting on expectations and attitudes, rather than a lack of ability, attainment or ambition in under-represented demographic groups.

Informal STEM experiences

Dou et al. in 2018 reviewed early STEM informal experiences to look for links to later attainment in STEM study choices through the lens of building a positive science identity. They write that considerable research connects early informal science learning experiences to science identity formation and note that this has been a "robust lens" to provide insights into STEM career choices, however, conclude that the relationship between these factors is still not fully understood [Dou et al., 2019].

They analysed a cross-sectional cohort of more than 15,000 young people looking for links to later STEM career intentions. They discovered that participants' likelihood of choosing a STEM career in college increased by 85% for every one-point increase on their STEM identity scale, however early STEM experiences were not all associated with increases in STEM identity. Out of 12 categories, only two — talking with friends or family about STEM and STEM experiences, and consuming STEM via the media were predictive of STEM career choices at college level. Dou also note that the consumption of STEM related media (e.g. books and TV related science or sci-fi) is fraught with stereotypical biases towards the representation of science and scientists. Once again, attention is drawn to the lack of role models representing the demographics of under-served communities, and the continued perception that science is the domain of white males [O'Keeffe, 2013].

The presence of STEM clubs in schools is reported to be an important positive factor in STEM study choices, offering a more informal way to enjoy STEM subjects without the performative requirements and testing of school lessons. Interestingly the existence of a STEM club in a school was associated with raised STEM study aspirations in school students across the board (even for students who did not themselves take part in it) with more people at schools with STEM clubs taking triple science choices at GCSE. Within those schools 60.1% of those attending STEM clubs progressed to triple science, compared to 46.5% who did not [Archer, 2020; Archer, Moote, Macleod et al., 2020; Davis et al., 2021]. This raises the possibility that science identity can be built at a collective level, for example, within schools, not simply at the level of the individual, but confirms that positive science identity is still a major factor in decisions about future study and careers.

Enrichment activities, careers advice and engagement

Recent research has for the first time, using robust randomised controlled trial (RCT methodology) established a positive relationship between young people's engagement with the world of work and their GCSE attainment [Kashefpakdel, Percy and Rehill, 2014]. This study and report found that part of the success of independent schools in transitioning students out of secondary education (including for university admission) was their extensive use of links with employers. Conversely, pupils (schools) with fewer links to employers were more likely to become NEET (Not in Employment, Education or Training). Four interventions/engagement (or more) by employers were observed to be the minimum number required in order to prevent students progressing to become NEET, and this work drove a 2007 Department for Education commitment to improving employment links with schools [Mann, Kashefpakdel et al., 2017]. Employer engagement has consistently been shown to increase earning potential and positively impacts student motivation by linking the curriculum to the world of work. Interestingly the linking of curriculum science to the world of work, and therefore to "everyday life" segues with the science capital teaching principles developed by the Aspires 2 research team [Archer, Moote, Macleod et al., 2020]. It should be noted that the work described in this section does not necessarily specify STEM disciplines, but many of the larger employers involved in careers engagement have STEM as a major or significant requirement of their future work-force, hence their presence in the careers advice sector.

An in-depth systematic review of the literature reviewing the evidence for the success, importance and efficacy of careers provisions in schools changing outcomes in pupils was undertaken by the Education Endowment Foundation in 2016 [Hughes et al., 2016]. They report that experimental literature on careers education is weak, however longitudinal studies suggest that how teenagers think about their futures in education and employment has a significant impact on their outcomes as adults in the workforce. Those who underestimate the educational attainment required for their desired profession are statistically more likely to end up NEET, it reports, saying further, that socio-economically disadvantaged young people are more likely to have a misalignment between educational ambition and their career aspirations, with this misalignment further embedding their disadvantage.

The report shows a strong link between part-time teenage work and employment outcomes, but also notes that part-time work in school pupils has decreased by more than half to just 18% in recent years, leaving other careers provision to provide the "careers capital" that might have been gained by being in part-time work, with the primary reason given (55%) that pupils wished to, or had been advised to concentrate on their formal studies instead [UKCES, 2015]. In keeping with numerous other reports, the Careers Review states that there is compelling evidence that careers information and engagement should start at primary school and not later [Watson and McMahon, 2005; Hughes et al., 2016]. Although these large-scale studies are not all specific to science or STEM disciplines, there is additional evidence to suggest that exposure to work before the age of 14 is associated with aspiration to or pursuit of a STEM career [Watson and McMahon, 2005]

As has been shown from a number of factors known to affect engagement with STEM and diversity, taking a person-centred approach appears to be effective [Lin, Lee and Snyder, 2018]. Results from a 2020 study showed that a student-centred approach and with multiple interventions was successful in engaging students with STEM and reducing unequal engagement; they showed that prior to the interventions, girls were significantly less likely than boys to know the following STEM jobs: surveyor, technician, and games tester. Following the sustained interventions, there was no significant difference between boys and girls. Furthermore, one of the STEM jobs, Engineering, showed the greatest increase in the percentage of boys and girls intending to enter the sector in after the interventions compared to before [Emembolu et al., 2020].

Despite reports from industry detailing significant engagement with schools, Engineering UK's Brand Monitor from 2019 reported that across the UK, although 34% of pupils (age 11-19 years) had taken part in some form of STEM activity, and 27% had done so in the last twelve months, just 1% had had a visit to or from industry in the previous year. There were no significant differences in access to engineering engagement by gender or ethnicity in this report, but the figure of 1% visits to or from industry suggests that there is some way still to go in establishing ongoing or in-depth engagement across the board in schools, and further yet before reaching the 'bar' of 4 interventions is achieved; the number statistically required for the interventions to affect outcomes [Engineering UK, 2019]. Although there is evidence therefore that person-centred engagement is successful in getting students from all demographics into further study or STEM careers, the number of school students currently in receipt of the necessary interventions in the UK is still devastatingly small.

Person-centred science engagement — examples from current practice

What evidence we have regarding equity of access to science engagement broadly points towards the necessity of facilitators and practitioners to deliver engagement activities or experiences which are a) deeper and b) repeated, in order to successfully develop science identities in individuals where they can interpret science and science engagement as "for me," [Archer, DeWitt, Davenport et al., 2021]. Several engagement programmes across the UK are using either the concept of repeated interventions within a cohort, or deeper immersion within the engagement activities, in order to achieve these aims within both formal and informal settings. While school interventions have the advantage of captive audiences and can be targeted at schools with specific demographics (for example, socio-economic disadvantage), in-school engagement also lacks the capacity for inter-generational learning and parent/guardian engagement, known to be vital in building science capital and forming science identities, and so a combination of formal and informal (community or family based) engagement types may be an optimal approach. One aspect which seems clear, however, is the idea of building engagement around individuals and the acknowledgement that putting the individual, their lives and experiences, at the heart of engagement is most likely to resonate and allow those individuals to interpret science as "for me".

The concept of "person-centred engagement" derives from healthcare, which identified the concept of "patient-centred care" (PCC) as long ago in the 1950s and 1960s and was developed in the 21st century. Defined as an approach to patient engagement which "encompasses qualities of compassion, empathy and responsiveness to the needs, values and expressed preferences of the individual patient," it recognises that focussing on a deficit (for example an illness to be treated) rather than engaging with the patient as a whole person may fails to adequately address psycho-social, cultural and other aspects of people that are vital for health and wellbeing [Byrne, Baldwin and Harvey, 2020]. There are parallels to science engagement, from old forms of engagement based on the deficit model of understanding to updated models which involve repeated, deeper, individualised engagements. While the WHO continues to advocate for person centred care, with a vision that "all people have equal access to quality health services that are co-produced in a way that meets their life course needs," so this framework can be seen to be an optimal way to provide equitable science engagement that meets the needs of all people, including those who are underserved and under-represented [World Health Organization, 2018].

One form of engagement which often relies on putting the individual at the heart of science engagement and research is the recent rise in 'citizen science' that is described as, "the collection and analysis of data relating to the natural world by members of the general public, typically as part of a collaborative project with professional scientists," [Bonney, Cooper and Ballard, 2016]. It is a process that involves scientists collaborating with segments of the general public to collect and/or analyse data for a research project [Lewandowski and Oberhauser, 2017]. The term 'citizen science' first appears in the academic literature in 1995 when used to describe how expert knowledge can exist in what was previously thought of as 'lay people' — or in other words people who do not hold professional qualifications in science [Irwin, 1995; Irwin, 2006; Irwin, 2008].

Citizen science is constituted by the participation of people who are not working professionally as scientists [Hecht and Rice, 2015]. This is an important distinction from Irwin's definition as someone who is not working professionally as a scientist may still have some degree of scientific knowledge, or indeed a science qualification. Citizen science projects provide a two-way benefit — both for the scientists and for the citizens involved in the project. Cohn argues that scientists can generate large quantities of data from citizen science projects. These data are supplied to scientists by the public (or the 'citizen scientists') i.e. those who are not traditionally involved in data collection and scientific research. On the other hand, the public who choose to take part in the project benefit from being involved in a research project which may lead to an increase in their personal understanding of science [Cohn, 2008]. In addition, scientists who use citizen science as a tool for data generation benefit from being able to generate large quantities of data over a large geographical area [Cohn, 2008].

However, there is some disagreement in the literature about what does and what does not constitute citizen science. For example, Hecht & Spicer-Rice argue that citizen science can include any type of public involvement in research such as completing surveys or participating in qualitative research, whereas Trumbull et al. [2000] argue that for something to be truly a citizen science project, the public must be involved directly in data collection and/or analysis [Trumbull et al., 2000; Hecht and Rice, 2015].

At a more nuanced level, taking participatory engagement to deeper levels, the role of storytelling and immersion in science communication has recently begun to be more deeply explored. 'The Science of Storytelling' by Storr explores and discusses how stories may be applied in science communication, recognising the effectiveness of immersion and personalisation in stories, and the role of 'narrative transportation, that is, to be so immersed in a story that an individual's behaviours and attitudes can be changed in real life [Storr, 2020]. Storr says "transportation changes people, then it changes the world". A brief review of the academic literature surrounding storytelling for the purposes of science communication, however, tends to focus on the benefit to the scientists of using stories to impart and communicate their research through story, rather than the effect on the audience [Kelesidou and Chabrol, 2021]. Nevertheless some forms of immersive and participatory engagement have emerged in the last few years, in which the individual is centred within stories, at the heart of the science engagement experience, and initial results from evaluations of these experiences suggest that these events can strongly engage individuals in science in a way which is both equitable and effective [Watson, Harvey et al., 2014; Keith and Griffiths, 2020]. This concept "science *is* for me" was explored and developed into the 'SCENE' model for inclusive engagement developed by Keith and Griffiths [Keith, 2021]. In it, the authors proposed a novel model for engaging underserved and under-represented audiences through a framework which was based in the community and which used narrative-driven engagement, placing the individual at the heart of a fictional STEM-based story. The primary driver for public involvement was entertainment, (in order to engage a non-captive audience), and it employed enquiry based learning within the narrative to engage young people and families with purpose-driven science content [Griffiths and Keith, 2021; Keith, 2021; Keith and Griffiths, 2021].

For both citizen science and more immersive forms of engagement, there are key similarities in the importance of the role of the participants in the experiences. Both citizen science and immersive theatre take person-centred approaches to engaging non-scientists with science. In both examples, the 'lay' person (participant) is central to the experience and the engagement experience values and needs their input to be successful. This subtle but important difference from some more traditional forms of engagement could be a key reason why both sectors are growing rapidly. The message that too many people experience 'science' as something that is "not for me" may now be being heard and acted upon.

In adopting a person-centred engagement approach, which also fits with Archer's paradigms for building Science Capital, we propose here a reframing of science engagement from 'science engagement for science' which stresses intrinsic benefits of science engagement to science, towards a new approach of 'science engagement for good' which stresses the external benefits of science to the individual.

Reimagining science engagement: a new conceptual framework

In this paper, we have explored some of the factors which are thought to affect equity of access to science engagement activities. These factors may help explain why audiences, participants, and visitors to science engagement activities have a tendency to attract white, middle class participants, to the exclusion of minority ethnic and/or working class visitors. The same lack of diversity is observed in the STEM work-force and it is proposed that inequitable access to science engagement is one reason why increasing the number of science engagement activities and funding in the UK have not translated into greater diversity of the STEM workforce. Despite many studies about inequity within science and science engagement, the underlying reasons why participation in science and science engagement for some communities is lower than for white, middle classes is less clear and requires further examination. Aside from the economic workforce imperative, STEM subjects are integral to social development and social mobility with STEM skills improving quality of life and likely to increase income by around 26% [Nath and Border, 2013]. We argue here that taking a person-centred approach to STEM engagement and focussing on reasons that will benefit individuals (rather than STEM industries or the economy), is most likely to result in equitable access to STEM engagement and future STEM study and career choices.

It is clear that STEM remains one of the most inequitable industries and is not yet representative of society, despite extensive programmes of outreach, widening participation, science communication and science engagement. The current framing; (that we need to do more science engagement to make science more diverse and representative of society), has often not resonated with those communities whom science engagement activities are targeted towards. This statement is supported by the UK Government's report into public attitudes of science which found that despite 72% of people having taken part in some form of science-related activity, only 1 in 5 felt actively connected with science [Castell et al., 2014; Research Councils UK and ComRes, 2017].

There is further evidence of success in a person-centred approach taken by Unicef in their "Sport for Development" (S4D) programme [Jessop, Chavez and Zapata, 2019]. S4D proposed that people engage with sport "for me", that is their engagement was framed around using sport as a means to achieve crucial individual outcomes for children and young people, such as learning, health, empowerment and protection, rather than the benefit for sport itself. S4D activities — like science engagement activities — come in lots of forms. They include activities and events that build personal and social programmes around sport, to those that use sport as a means to achieving social goals. Broadly speaking, S4D projects aim to promote positive outcomes in key areas, using sport as a theme to achieve societal goals: education, social inclusion, child protection, empowerment, health and peace building [Jessop, Chavez and Zapata, 2019]. The power of sport is used to improve the lives of those taking part in the S4D activity or event — usually children or young people. The activities use sport as a means, not as an end, and the focus is on using sport to educate, promote social inclusion, protect children and empower participants. Unlike many science engagement events, S4D is about the needs of the individual, rather than the needs of the sector.

An example of a S4D programme that is focused on the needs of the children and young people (rather than the needs of sport) is the work of UNICEF in Eastern Ukraine, where the sounds of war are all too familiar for the children who play football — or rather, played football — before Russia's widespread invasion of the country. UNICEF have used S4D to help thousands of children, young people and their caregivers alleviate the burdens of war whilst also using sport as a means to provide psychosocial support to help the children and young people make sense of the world and manage the stress of life living in a conflict zone [Silina, 2018]. Within the UK, a leading S4D organisation is Sported which sets out to use sport as a means to allow every young person to fulfil their potential, help community groups survive, and young people thrive. Their objectives are around using sport as a means to develop mental wellbeing, tackle inequalities through sport, and connect communities for collective action [Sported, 2021]. Values are placed at the heart of these objectives: integrity, inclusion, people-led and change-driven. Through engagement with community groups, this organisation and many others have impacted the lives of many children and young people, using sport as a means to address: community cohesion; crime and anti-social behaviour; education and employability; and wellbeing [Skinner, Zakus and Cowell, 2008].

There are parallels to be drawn between participation in science and sport. Anyone can participate in sport — it is after all, by definition, any form of physical activity. Those who train hard, are gifted and have the optimal environment to participate and train, can develop and participate/compete at professional levels. Likewise in science, an enthusiasm for asking questions, understanding how things work, exploring nature and technology can be the markings of a budding scientist, who can then train, study and participate in creating knowledge at a professional level.

We propose that science engagement learns from the success of S4D in using science as a means for individual personal development rather than a means to address problems within the STEM sector. S4D initiatives have been shown to improve attainment of life skills, empower participants, improve self-esteem, enhance leadership skills and help young people create better relationships with adults [Jessop, Chavez and Zapata, 2019], and these outcomes are needed within the STEM sectors. The culture of S4D creates a culture of positive participation in sport, and this has been shown to reduce violence and tackle social and structural inequity — issues that affect science as much as sport.

In reframing science engagement, we propose a conceptual model that shifts away from trying to increase an individual's interest in science, but rather promotes engagement with science 'for good' reasons defined in the six pillars of 'science engagement for good' (Figure 1)

We propose that the purpose of science engagement activities must have achieved at least one of the six outcomes highlighted in Figure 1 in order for it to be meaningful for the individual. This re-think on science engagement encourages those producing and delivering science engagement events to shift the framing of the event away from issues around science workforce and equity in science, towards one or more of these six desired outcomes:

1. Participation in science engagement events/activities will enhance mental wellbeing and/or encourage healthy lifestyle behaviours
2. Participation in science engagement events/activities will promote equality and empower marginalised groups
3. By participating in the science engagement events/activities, the individual will develop key employability skills such as teamwork, problem solving, communication and presenting skills
4. The science engagement events/activities will create a safe community space that embraces ethical, cultural and physical differences and promotes the sharing of cultures between different communities
5. Participation in the science engagement events/activities will directly lead to increased access to and completion of education

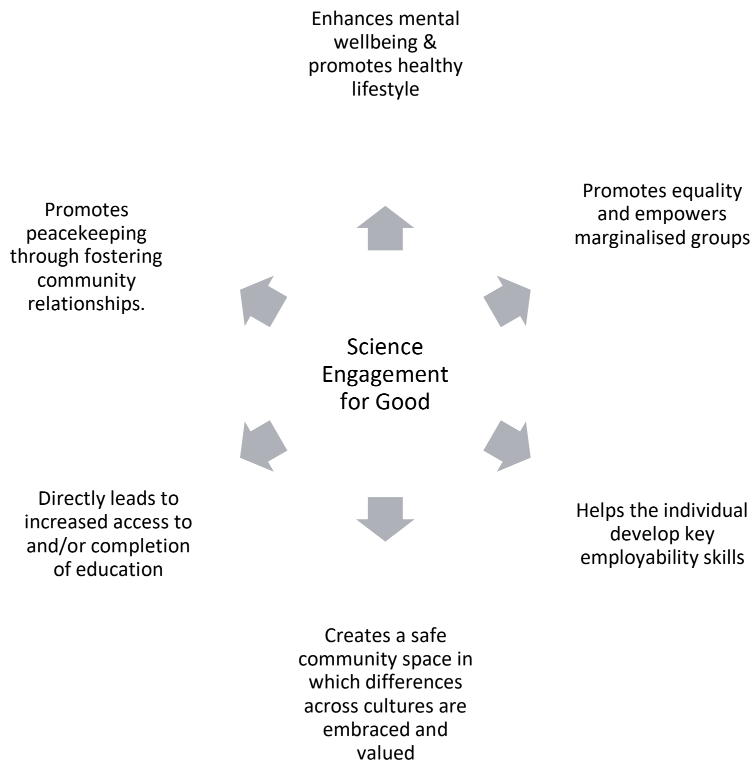

Figure 1. Science engagement for good. A new conceptual model framing science engagement as a benefit to the individual, rather than a benefit to science.

6. Engagement with science event/activities will help will actively promote peacekeeping[1] through fostering relationships between different groups

Conclusion

Science engagement, and uptake of science, is affected by a number of factors but the intricate detail of how these factors affect participation remains under-researched, so there is no joined-up approach to solving inequity within science engagement. Inequity in science and science engagement is not only a social justice issue but is an economic issue. A more diverse and skilled STEM workforce is essential to meet the demands of the market to enhance the UK's STEM economic productivity; however, the framing of science engagement as a means for the UK to be more productive economically continues not to resonate with those communities that science engagement events seek to engage.

Science remains characterised by a lack of diversity and dearth of role models, particularly women, disabled, LGBTQ+, and people of colour — all of whom are less represented in the STEM sector than the general workforce. Our proposed model 'science engagement for good' seeks to address science inequity through a reframing and refocus of science engagement activities. Science engagement can no longer focus on stressing intrinsic benefits to science, but must now focus on stressing benefits to the individual in participating in science.

[1] In the Unicef Sport for Development model this has referred to peacekeeping across lines of international conflict, or civil warfare but in the UK this may be reflected in crossing sectarian lines or other sources of internal community conflict.

Finally, science — like sport — will never be the answer to all the challenges that children and young people face. There are of course many advantages of science adopting this new conceptual model which embeds good practice from S4D initiatives. Indeed, there is a correlation in S4D programmes with those which spend a higher amount of time playing sport having a higher number of children dropping out. So, there is a need to balance sport and social intervention, and science must also balance the science and societal aspects. Children and young people may join science engagement activities for science, but through the application of this conceptual model, they may stay for personal development and wider support. This can only be achieved when science engagement is about providing opportunities for individual personal development, rather than solving the challenges within the STEM sector. A rethink on science engagement as described here may sow the seeds for change.

Appendix A. Definitions

There are a wide range of definitions of concepts used throughout the informal science engagement sector, with some concepts often used interchangeably. It has been noted by many that these definitions are mutable and often used differently in different contexts and by different users and authors. (For the purposes of this report, we are using the following definitions, but this is not considered definitive — indeed, no such definitive glossary exists and even if it did, there is no agreed international standard convention for usage.)

Access refers to the opportunity that a person has to approach or enter a place. In the informal science engagement context, access refers to the opportunities (or lack thereof) that a person has to participate in informal science learning activities such as attending a science festival, science museum, joining an afterschool science club and so on.

Impact is a term that was first introduced to the Research Excellence Framework (REF) in 2014. Impact is defined within REF as an effect on, change or benefit to the economy, society, culture, public policy or services, health, the environment or quality of life, beyond academia.

Inequity refers to a lack of fairness or justice. In the informal science engagement context, inequity can refer to an unequal or unjust distribution of resources and opportunities to engage in informal science activities and events among members of a particular community (including but not limited to communities based on race, gender, sexuality, culture, and geography).

Informal science engagement (or informal STEM engagement) are opportunities for people to engage in science in an informal setting. It can include things like visiting museums, science festivals, watching YouTube science videos and participating in other science activities and events usually outside of school (for young people). Informal science engagement is particularly important for young people from disadvantaged backgrounds, who are more likely to find science subjects unengaging and difficult at school [Lloyd et al., 2012].

Public (or 'the public' or 'general public') refers to everyone in society who is neither a scientist nor part of a particular research community. It refers to everyone. Within the informal science engagement sector, this term is often frowned upon as it groups everyone together and does not take into account the diversity of the general public. Many of those working within science engagement use the pluralisation of public (publics) to highlight that the public is diverse and made up of countless segments.

Public consultation (or 'public comment' in the USA) is a regulatory process by which the public's input is sought on matters that affect them. It often refers to new legislation being proposed where public input on new policies or laws is sought.

Public dialogue is a two-way process by which members of the public interact with scientists or other science stakeholders (e.g. funders, science industries, policymakers) to discuss issues that are relevant to future decisions on science policy.

Public engagement with science, (PES, or simply PE) also referred to as "science engagement" refers to the various ways in which the activity and benefits of science and research can be shared with the public. It is often seen as a "two-way process" that involves some degree of interaction and listening on both parties (scientist and public).

Public involvement is a term that is becoming more commonplace within informal science engagement. Its origin is in health research and it means that research is done 'with' or 'by' the public, and not 'to', 'about', or 'for' the public. Often it means that patients (or people with relevant lived experience) contribute to how research is designed, conducted and disseminated.

Public understanding of science (PUS) is a concept with dual meaning. Firstly, it refers to a field of study relating to the study of the attitudes and understanding that the public have with science. Secondly, it refers to the public's attitudes and understanding of scientific concepts and developments in science. Within modern day informal science engagement, this concept is rarely in use as it is seen as out-dated and has been replaced by 'public engagement with science'.

Science communication refers to the communication of scientific knowledge and practices from those with expertise to those without expertise. Often, it is viewed as a 'one-way' flow of information from expert to lay person, but this is not always the case. One-way flow of information could involve a science journalist or broadcaster explaining science on TV, radio or in print media. However, science communication could also refer to scientists sharing findings with other scientists at conferences and it could involve scientists or science communicators explaining science at a science festival. Science communication is often seen as an umbrella term for a wide range of activities, including those in an informal setting.

Science communicator is the term for a person who communicates scientific concepts in understandable ways to non-specialists. Often, this may be a job title within a science centre or science festival. It could also be a scientist who is actively involved in informal science engagement with the public, where they are seen to communicate their research with wider non-specialist audiences. As with the term 'science communication', there is a wide range of roles to which the person fulfilling them may be classified as a science communicator.

Science engagement professional (STEM engagement professional, or public engagement professional) is becoming an increasingly popular term for professionals that work within the informal science engagement sector. It is also becoming more common as a collective term for those who work within the science and research sector (including universities) who are operating at a strategic or operational level to help researchers create and deliver public engagement activities and/or create, deliver and evaluate impact of scientific research and developments.

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