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A Theory of Change for improving children's perceptions, aspirations and uptake of STEM careers.

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Corresponding Author:	Carol Davenport Northumbria University Newcastle Upon Tyne, UNITED KINGDOM
Corresponding Author Secondary Information:	
Corresponding Author's Institution:	Northumbria University
Corresponding Author's Secondary Institution:	
First Author:	Carol Davenport
First Author Secondary Information:	
Order of Authors:	Carol Davenport
	Opeyemi Dele-Ajayi
	Itoro Emembolu
	Richard Morton
	Annie Padwick
	Antonio Portas
	Jonathan Sanderson
	Joe Shimwell
	Jane Stonehouse
	Rebecca Strachan
	Leanne Wake
	Gary Wells
	John Woodward
Order of Authors Secondary Information:	
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	choosing a career in STEM post-18?" An innovative ToC is introduced which provides the theoretical underpinnings and context for the complex mix of interventions necessary to lead to a significant change in the number and diversity of those choosing STEM careers. Case studies of interventions developed using the ToC are presented. This approach, and associated ToC, is widely applicable across STEM, education and public engagement fields.

A Theory of Change for improving children's perceptions, aspirations and uptake of STEM careers

Carol Davenport*[a], Opeyemi Dele-Ajayi[a], Itoro Emembolu [a], Richard Morton [a], Annie Padwick [a], Antonio Portas [a]; Jonathan Sanderson [a], Joe Shimwell [a], Jane Stonehouse [a], Rebecca Strachan[a], Leanne Wake [a], Gary Wells [a], John Woodward [a]

[a]*Faculty of Engineering and Environment, University of Northumbria at Newcastle, Newcastle Upon Tyne, UK, 0191 227 3650*

* carol.davenport@northumbria.ac.uk

0191 227 3650

Carol Davenport. Orcid ID: https://orcid.org/0000-0002-8816-3909
Opeyemi Dele-Ajayi https://orcid.org/0000-0001-6779-4421
Itoro Emembolu https://orcid.org/0000-0002-5765-4668
Richard Morton https://orcid.org/0000-0001-5678-9002
Annie Padwick https://orcid.org/0000-0001-9042-0209
Antonio Portas http://orcid.org/0000-0001-9897-9832
Jonathan Sanderson http://orcid.org/0000-0003-1769-8647
Joe Shimwell https://orcid.org/0000-0003-3211-1541
Jane Stonehouse https://orcid.org/0000-0001-7296-7454
Rebecca Strachan https://orcid.org/0000-0003-3694-2158
Leanne Wake https://orcid.org/0000-0003-1531-6473
Gary Wells https://orcid.org/0000-0002-8448-537X
John Woodward https://orcid.org/0000-0002-4980-4080

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Keywords: children and young people, diversity, STEM education, careers, Theory of Change, Science Capital

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Declaration of interest statement

The authors declare that there are no conflicts of interest.

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ABSTRACT

There is concern about the low numbers and diversity of young people choosing careers and study in science, technology, engineering and maths (STEM) subjects at university and beyond. Many interventions aimed at addressing this issue have focused on young people aged 14+ years old. However, these interventions have resulted in little improvement in the numbers and diversity of young people progressing into STEM careers. The aim of this study is to ask 'What are the affordances of a Theory of Change (ToC) for increasing the diversity and number of young people choosing a career in STEM post-18?" An innovative ToC is introduced which provides the theoretical underpinnings and context for the complex mix of interventions necessary to lead to a significant change in the number and diversity of those choosing STEM careers. Case studies of interventions developed using the ToC are presented. This approach, and associated ToC, is widely applicable across STEM, education and public engagement fields.

KEYWORDS: children and young people, diversity, STEM education, careers, Theory of Change, Science Capital

Introduction

This research paper outlines the development of a Theory of Change (ToC) to shape child-focussed Science, Technology, Engineering, and Mathematics (STEM) interventions of an Outreach Project in the North East of England. The aim of the project is to increase the diversity and number of young people choosing further study and a career in STEM.

The ToC developed identifies how children, young people and their teachers and families can be engaged to increase the diversity and number of young people choosing STEM careers. The development process for the ToC, and the ToC itself, are presented, together with brief case studies to illustrate the creation of different interventions using the ToC. Finally, the implications for policy and practice for other organisations active in STEM education are discussed.

Background

Governments and industry across the globe have been considering diversity issues in STEM around gender, race and socioeconomic status for over 40 years, often expressed in terms of the productivity and economic cost to each country's economy (see, for example, Noonan [2017]). Numerous other reports have focused on the uptake of STEM by women (Greenfield 2002; DfES 2004; Masanja 2010). There are also issues of under-representation in STEM around race (National Science Foundation 2017) and socio-economic status (Chetty, et al. 2017; HESA 2018).

There have been many attempts to rectify this lack of diversity in STEM in the UK, focussed on altering school curricula, making STEM more attractive to women and other under-represented groups, and improving career advice. Whilst the number of young people studying some STEM subjects at university has increased, limited progress has been made on changing the diversity of the young people interested in a career in STEM, particularly outside of the biological sciences.

The continuing lack of diversity of young people engaging in physical sciences, technology and engineering study suggests that the standard narratives and solutions for increasing uptake and diversity of STEM careers are not working. Archer et al. (2015) introduced the term 'science capital' to describe a number of factors correlated with expressions of interest towards science careers in young people, including science related attitudes, values and dispositions, knowledge about the transferability of science, talking about science in everyday life, and knowing people in science-related jobs.

Young people with high levels of science capital are more likely to express a desire for a future science career (DeWitt, Archer and Mau 2016).

A ‘wicked problem’ (Rittel and Webber 1973) is one that has many causes which are interlinked, and consequently does not have one single, simple solution. Increasing the number and diversity of young people choosing a STEM career is one such ‘wicked problem’. For example, whilst the gendered subject choices of young children have their roots in the individual’s experience of learning in school, subject choice also depends on the gender socialisation they have experienced through their families, the media they consume, and their role models. As a consequence, any solutions which are posited will also need to be wide-ranging and address the breadth of identified causes.

The aim of this paper is to explore the research question: What are the affordances of a ToC for increasing the diversity and number of young people choosing a career in STEM post-18? Additionally, the following sub-question will also be addressed: What are the affordances of a ToC for shaping the design of activities aimed at supporting young people to choose a career in STEM?

Theoretical underpinnings

In order to increase the number of young people choosing a career in STEM, those young people will need to exhibit specific behaviours at certain ages: at age 16+ they need to choose study options which will allow them to continue in STEM (A-levels and/or vocational qualifications); and at 18+ they need to choose career options (either further study, apprenticeships or work) within a STEM sector. Changing behaviour and attitudes in people is challenging (Institute for Government 2010). Ajzen (1985) proposed that the intention to perform a behaviour can be used as an accurate predictor of whether a person will actually perform the behaviour. These intentions are informed by a person's beliefs about success and failure and the subjective norms (attitudes towards the behaviour) of people that s/he considers significant. This Theory of Planned Behaviour can therefore be used as a theoretical basis to explore the connection between a young person's intention to exhibit a particular career behaviour at the ages of 16 and 18 and the attitudes, subjective norms and perceived behavioural control that influence the behaviour.

Stakeholders in STEM career choices

Children's career choices are influenced by family members, teachers and careers advisors (Wellcome Trust 2013a). These key influencers[1] help shape the subjective norms related to particular career-related behaviours.

Children and Young People

Using 'science capital' as a lens to understand young people's choice of science, and by extension STEM careers, DeWitt, Archer and Mau (2016) suggest there is a need to move the narrative away from inspiration and towards showing the application of science to increase science participation.

For young children, career interests are relatively fluid (Helwig 2003), however, from about age 5 – 6 they start to make career-limiting decisions about what they *do not* want to do (Gottfredson 2005; Bian, Leslie and Cimpian 2017). The factors that

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[1] It is recognised that there are other stakeholders with a strong interest in the career choices made by young people including higher education, industry, business and government. However, immediate and direct influence on these stakeholders was beyond the remit of the Outreach Project team that developed the Theory of Change.

influence these decisions include perceived gender-appropriateness of careers, social level of careers and accessibility (Chambers, Kashefpakdel, Rehil and Percy 2018), as well as the young person's concept of their own ability (Nagengast and Marsh 2012).

Teacher influence at primary and secondary school[2]

As young people become more sophisticated in thinking about their careers they begin to seek information about future possibilities from a range of different sources (Howard and Walsh 2010). Teachers are considered one of the most used, and useful, source of careers information by young people (Wellcome Trust 2013a).

The majority of children in primary schools in England are taught science and maths by teachers who do not have an advanced science or maths qualification (Wellcome Trust 2013b) and may also have limited/stereotypical views of STEM and people who work in STEM (Breiner, Johnson, Koehler, Harkness 2012).

Science teachers in secondary school may have a subject specialism but are also likely to be teaching all three sciences (biology, chemistry, and physics) to pupils aged 16 and below. Thus even specialist teachers, when teaching 'out of field' may have areas of the curriculum they are less confident to teach (Hobbs 2013), and this in turn can affect how young people in their classes view those subject areas (Salleh and Darmawan 2013).

Teachers can also affect children's and young people's career choices through stereotyping and unconscious bias. These can have detrimental effects in the classroom, particularly through teachers' interactions with children (Van den Bergh, et al. 2010;

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[2] In England, primary school pupils are between the ages of 3 – 11 and secondary school pupils between the ages of 11 – 16 (or sometimes 18).

Lavy and Sand 2015) and their expectations of student achievement (Tan, Calabrese Barton, Kang and O'Neil 2013).

The importance of Parents

Family members are seen by young people as their most important source of careers information (Wellcome Trust 2013a) and so parents and carers[3] are the third group of stakeholders in young people's career choices. The association between parental involvement and a child's educational achievement is well established (Goodall, et al. 2011) with activities that promote conversations about school experiences in the home being directly correlated with children's achievement in school (Desforges and Abouchaar 2003).

Alongside the effects of previous negative science-related educational experiences or lack of confidence, bias (conscious or unconscious) can also affect the level of educational support that parents provide to their children, and the career aspirations that they may consider appropriate. Gender is one of the strongest factors to affect a child's development in any society (Bem 1993) and the social and career roles considered appropriate for a child often depend on the perceived gender of the child (Miller and Hayward 2006). Parents of daughters are less likely to believe that their child is interested in science and that science is more difficult for their child than parents of sons (Tenenbaum and Leaper 2003), and parents can share gender-

[3] Although much of the literature in this section refers to 'parents' it should be recognised that children may also be living with others who are acting in loco parentis and that these carers will also have influence on the children and young people.

stereotyped views of occupations with their children (Ikonen, Leinonen, Asikainen and Hirvonen 2017).

Addressing the 'wicked problem' of diversity in STEM

Any effective solution must be able to address the complexity and long timescales involved and treat the 'wicked problem' of diversity in STEM, and its solution, holistically. The ToC described in this paper is robust enough to accommodate and explicate how different stakeholders can be engaged to increase the number and diversity of young people choosing a STEM career. The strategy outlined encompasses children from the ages of 2 to 18 years alongside their key influencers: parents and teachers, and provides a strategy for solving the 'wicked problem' in the long term.

Methodology

Outreach Project background

The aim of the Outreach Project was to increase the number of young people choosing to study physics, and physics-related degrees (including those in engineering and technology), with particular focus on increasing diversity through greater participation by females and people from lower socioeconomic backgrounds. Previous efforts to achieve this aim have been focussed on secondary school pupils and have met with limited success. The project therefore chose to work with children and young people in primary schools, as well as secondary schools. The Outreach Project worked with around 30 partner schools covering the age range from 2 years to 19 years old, and provided ongoing interactions with children and young people, as well as their teachers and families, initially for three years. The project was a partnership of 10 organisations, including local authorities, visitor attractions, STEM organisations and the university where the outreach team was situated. The majority of the schools engaged in the project were in areas of deprivation[4].

The broad age range of children and young people involved in the Outreach Project means that evaluating the impact of the project in relation to its stated aim is not possible for all participants because after three years, children in primary school will not be at a point of career decision making. Dyson and Todd (2009, pg. 124) note that ToC evaluations 'rely on predicting what outcomes might emerge as much as identifying outcomes that are already apparent. Outcomes in ToC evaluations are conceptualized as materializing at the end point of a change of intermediate changes which the evaluation seeks to track.'

This feature means that a ToC approach is particularly suitable for evaluating the outcomes of interventions in complex contexts such as education, or in situations where the outcomes emerge after the completion of the intervention (Dyson and Todd 2009) as in the case for the Outreach Project.

Theory of Change

ToC approaches were initially developed in the US as a way of evaluating complex community initiatives (Murray and Stewart 2006) but have been used in the UK as a way to evaluate policy initiatives such as Full Service Extended Schools (Dyson and Todd 2009).

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[4] The percentage of pupils that received government funded school lunches (free school meals) in a school was used as a proxy for the level of deprivation of the community within, and around, each school.

Developing a ToC involves ‘a systematic and cumulative study of the links between activities, outcomes and context’ (Connell and Kubisch, 1998, p.16) and provides ‘an overarching framework for understanding, systematically testing and refining the assumed connections (i.e. the theory) between an intervention and the anticipated impacts.” (HM Treasury, 2011, p. 57). They can be particularly useful in the evaluation of complex interventions where it is difficult to identify or track the endpoint outcomes of the intervention (Connell and Kubisch, 1998, Dyson and Todd, 2009). Once the first step of identifying the final impact or change that the programme or intervention is intended to bring about is completed, a process of backward mapping is undertaken and intermediate outcomes that are required to achieve this goal are articulated. This mapping process helps to surface the explicit or implicit theories that are held by those involved in developing the intervention. Intermediate outcomes may be short-, medium- or long-term. Together the outcomes will create a causal pathway which supports the final goal of the programme (Taplin, Clarke, Collins, Colby 2013). A ToC is both a process and a product (Vogel 2012) therefore an iterative approach can be helpful.

Process used to develop the ToC

The Outreach Project was a multi-year intervention, with an intended long-term evaluation of children’s qualification choices planned using the National Pupil

Database[5] which will take place ten years after the start of the project in primary schools. However, evaluation of the project on a short-to-medium term timescale was also required. Rather than relying on short-term evaluation of individual activities, a ToC approach was chosen to allow the evaluation to be clearly linked to the project's long-term aim through a chain of intermediate outcomes which are more amenable to tracking and evaluation (Dyson and Todd, 2009).

At the beginning of the Outreach Project, a simple model was produced outlining the journey of a child through different activities, ages and stages, along with complementary activities for key influencers (Figure 1). This was a first step in development of a ToC and enabled the development of a narrative understanding of the expanse of the STEM ecosystem in which children make decisions about careers. However, it did not allow for a clear elucidation of the behaviour changes and linked subjective norms required to lead to an increase in young people choosing a STEM career. Creating and using a detailed ToC allowed the development of a layered series of outcomes encompassing short-, medium- and long-term time-scales, and guided the level and nature of evaluation of the intermediate stages.

Fig.1 Simple diagram showing the educational journey of a child and their key influencers, and the changing nature of activities during that time

[insert Figure 1]

[5] The National Pupil Database is a collection of data relating to education in England collected by the Department for Education. It includes information on schools workforce and pupils, national curriculum tests and public examinations. Records are held from 2006, and all pupils have an unique identifier that allows their education to be tracked.

The ToC was developed through an iterative series of workshops with members of the Outreach Project team and other academic staff within the university. Backward mapping was used to clarify the steps required to attain the overall aim of the project: increasing the number and diversity of students choosing a career in STEM post-18 (see bottom of Figure 2).

The backward mapping process began with a workshop which involved the core delivery team of the outreach project and two academic staff from the university. Firstly, key stakeholders with an interest in the project aim were identified: these included children and young people, teachers and schools, parents and families, companies in different STEM sectors (both locally and nationally), further and higher education institutions, and government. However, the project team realised that aiming to work directly with all of these stakeholders was unrealistic. It was therefore important to narrow the range of stakeholders targeted. The choice of key stakeholders is supported by the Theory of Planned Behaviour (Ajzen, 1985) and the importance of subjective norms on the intention to try a particular behaviour. Children and young people are the ones whose behaviour we are aiming to change, but parents and teachers are the referents (significant others) that strongly influence the subjective norms, and whose views children and young people are (usually) motivated to comply with. The more a child believes that parents and teachers think they should exhibit a behaviour, then the stronger the subjective norm towards that behaviour will be. Therefore, it was important that the key stakeholders described by the ToC would allow influence and change to be effected on those subjective norms. For this reason, in addition to children and young people, the project team identified teachers and parents/carers as the stakeholders that were key to the impact of the project in the North East. This narrowing of stakeholder focus also allowed the team to identify the level of evidence at which impact could be measured (Kazimirski and Pritchard 2014).

Having identified the key stakeholders the group then started with the aim and worked backwards in time to consider what attitudinal, behavioural and structural changes for those stakeholders would need to occur to achieve the aim– the backward mapping .

This was an iterative process. The group first worked individually to identify the interim changes required for each group of stakeholders, writing each potential change on a post-it note. The choice of changes was informed by previous examination of the research literature, and also professional expertise. This identification process resulted in a large number of possible changes written on post-it notes. Two members of the group then worked together to group the notes by theme for each stakeholder group, and to categorise them into long-, medium- and short-term changes. The validity of the groupings and categorisation were then discussed by the group as a whole, and changes made to the organisation until consensus was reached.

The discussions identified long-term outcomes for the project as shown in Figure 2.

Fig.2 ToC showing short-, medium-, and long-term outcomes linked to increasing diversity in STEM

[Insert Figure 2: Theory of Change diagram]

For children and young people two long-term outcomes were identified: '*Increased confidence in ability to study STEM post-16'*[6] and '*Increased number choose to study A-level or vocational qualification in STEM subjects'*. These two outcomes link to the changes in behaviour required at age 16 to enable young people to progress into STEM careers at age 18 (project aim). Improving a young person's attitude towards success through increased confidence will increase the likelihood of them choosing to exhibit the desired behaviour (Ajzen, 1985).

For schools the long-term outcome '*School environment mitigates effects of bias and stereotypes'* was identified as important, and for parents and carers the long-term outcome identified was '*Parents and carers support and encourage STEM career choices for their children'*.

To achieve these longer term aims other medium-term changes were required. These changes were categorised to create a number of medium-term outcomes for each stakeholder group which were those that were expected to develop as a consequence of repeated interactions, or which were time-critical to the school year or maturity of the children and young people.

A final round of mapping took place to identify short-term outcomes which fed into the medium-term outcomes, and the overall ToC diagram created (Figure 2). There are often many-to-many relationships between the different outcomes. This is due to the complex nature of the system within which the project is situated. The project team used the categorisation of short-, medium-, and long-term outcomes to identify causal

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[6] The phrases in italics are long-term outcomes, medium-term outcomes or short-term outcomes taken from the ToC

chains which linked the short-term outcomes with the long-term outcomes. Figure 3 shows an example of one such causal chain taken from the ToC.

Fig.3 Example of a causal chain in the ToC linking together the short-, medium, and long-term outcomes

[Insert Figure 3 Example of a causal chain]

Having created a first draft of the ToC, the outreach team then audited a number of the interventions that had already been developed and delivered in schools against the draft ToC. This audit was focussed on two questions (a) does the ToC accommodate the intervention and (b) does the ToC have something to say about the value of that intervention. The audit identified a number of causal links that had not been included in the initial mapping (for example, including an explicit link between medium-term outcomes for the family and child stakeholder groups), which were then added. The audit also caused the outreach team to change the focus of some of the interventions, with the activities becoming more explicitly careers-centred as a result.

After the draft was produced, each outcome was cross-referenced to relevant research literature to ensure that the ToC was supported by prior research (see supplementary material S1 for an overview of supporting research literature).

To further increase the confidence in, and trust-worthiness of, the draft ToC it was shared and discussed with the advisory and management bodies of the Outreach project. These groups included representatives from formal and informal education, industrial and charitable groups. The comments from these discussions were then used to finesse the ToC.

Developing interventions using the short- and medium-term outcomes

A number of case-studies are presented in Table 1 which illustrate interventions that have been developed using the ToC. These case studies were chosen to represent the breadth of academic STEM subjects included in the Outreach Project overall and provide examples of collaboration between the outreach team and other research-active academics.

The ToC applies to all parts of a child's educational journey, but the nature of the interventions developed to meet the outcomes change as the child gets older. For children aged between 2 and 5 years old, workshops focus on encouraging children to ask scientific questions, and provide opportunities for role-play based around different employment sectors. Between the ages of 6 and 11 years, children are introduced to a range of different STEM careers through exploratory workshops with titles such as the Solar Physicist (solar system and light) and the Mechanical Engineer (gears and simple mechanisms).

At secondary school (age 11 – 16 years), support is focussed on careers ideas and information through workshops and assemblies, and on sustaining young people's identification as a 'STEM person', together with the provision of careers-linked subject resources for use in the classroom. Once a young person has chosen to study physics and maths at 15-16 years old, the focus moves to activities aimed at supporting both attainment and self-concept as a 'STEM person', such as research experience weeks, networking events and after-school lecture series. These are designed to reduce the drop-off in STEM aspirations often seen at this age.

To support the short-term outcomes for teachers, CPD sessions about science topics, careers support and unconscious bias are provided to schools. In addition, science coordinators in primary schools are invited to attend a Primary Science

Coordinators Forum six times a year where they are supported to strengthen the teaching of science and STEM in their schools.

Families are engaged through after-school workshops, holiday pop-up STEM shops and online materials. These activities challenge the gendered expectations of different careers, through careful activity design and delivery which removed gendered language, images and role models, and normalise scientific enquiry and science conversations for all participants: adults and children.

[Insert Table 1: Case studies of different interventions linked to short- and medium-term outcomes from the ToC]

Discussion and Conclusion

This paper has aimed to answer the research questions "What are the affordances of a ToC for increasing the diversity and number of young people choosing a career in STEM post-18" and "What are the affordances of a ToC for shaping the design of activities aimed at supporting young people to choose a career in STEM."

Using a ToC enabled the identification of causal chains that could realistically lead to a long-term increase in the diversity and number of young people choosing a STEM career, and provided the theoretical underpinnings and context for those causal chains. Given the extended time-scale required to achieve this increase, using a ToC provides a way of evaluating the interim steps towards the aim of the project. The case studies provide examples of how the ToC is used in practice to underpin the development of each intervention and outlines the impacts on the young people and/or their key influencers.

One of the affordances of using a ToC process in STEM education and engagement is that it allows the development of solutions to complex problems in a structured way. The ToC developed here provides a mechanism to connect together a number of causal chains which, taken together, provide a plausible solution to increasing the diversity and number of young people choosing a STEM career. Two key aspects of the solution are the identification of the key stakeholders in the ToC, namely, children and young people and their key influencers (parents and carers, and their teachers). It can be seen that the short- and medium-term outcomes are strongly interlinked with each other, highlighting the need for coordination and planning across the STEM engagement sector as a whole.

Developing a ToC for an outreach project provides clarity when developing individual activities, and offers a mechanism through which the desired outcomes can be made explicit for all the stakeholders in the project. The authors have found the development of the ToC presented here to be beneficial in their own practice, in developing strategies towards that practice and in conversation with others. The ToC offers both predictive and diagnostic utility, of individual activities and of an overall programme of work, assisting the authors in recognising where their practice has strengths and limitations. The ToC also encourages a cycle of review and reflection and has provided a route for the Outreach Project team to reflect on their own practice and clearly articulate their vision and aim to others.

As well as identifying causal chains, a ToC takes into account the pre-requisites and assumptions that underlie them, along with the barriers which may work against them (supplementary material S2). The Outreach Project aims to increase the number and diversity of people in STEM careers through repeated and ongoing interactions with children and their key influencers. In achieving this aim, a ceiling of accountability can be identified which is the ‘Level at which you stop using indicators to measure whether the outcomes have been achieved and therefore stop accepting responsibility for achieving those outcomes' (De Silva et al. 2014, p.5). Ultimately, the longer-term outcomes are beyond the control of the Outreach Project. For example, the long-term outcome *Increased confidence to study STEM post-16* is a personal psychological attitude in individuals. This therefore sets the ceiling of accountability for the ToC. Similarly, the ToC does not include industry bodies or companies. For a long-term solution, these organisations will also need to improve their recruitment and retention of staff (Airbus 2018).

However, even with the limitations identified, this approach and ToC have wide applicability across STEM, education and public engagement fields. For example, the ToC has utility across the wider STEM engagement community where activities may be of a shorter timescale or more limited scope than those of this Outreach Project. Using this broad ToC allows a community to identify individual activities that can be developed and aligned within the structure of short- and medium- term goals, yet still contribute to long-term goals. This should help increase their likely effectiveness rather than taking a purely short term view. It also allows identification of potential measures of success for evaluation of activities.

The ToC could also be applied by those responsible for career guidance within school or college settings to ensure they are supporting the long-term goals for the career aspirations and perceptions of those young people.

Ultimately, solving the STEM skills shortage requires a number of nested Theories of Change, each developed by the key actors within the STEM space. These actors include companies, learned societies, governments and charities. The authors recommend that each organisation looking to improve the uptake of STEM careers articulates their expected impact through a ToC, utilising the ToC described in this paper as a guide, and that they openly share their ToC with others. This would have two affordances: it would identify clearly how change is to be achieved, and it would allow a more holistic approach to encouraging young people to enter, and remain, in STEM careers. Working in partnership in this way is essential if the ‘wicked problem’ of diversity in STEM is to be tackled effectively in a realistic fashion.

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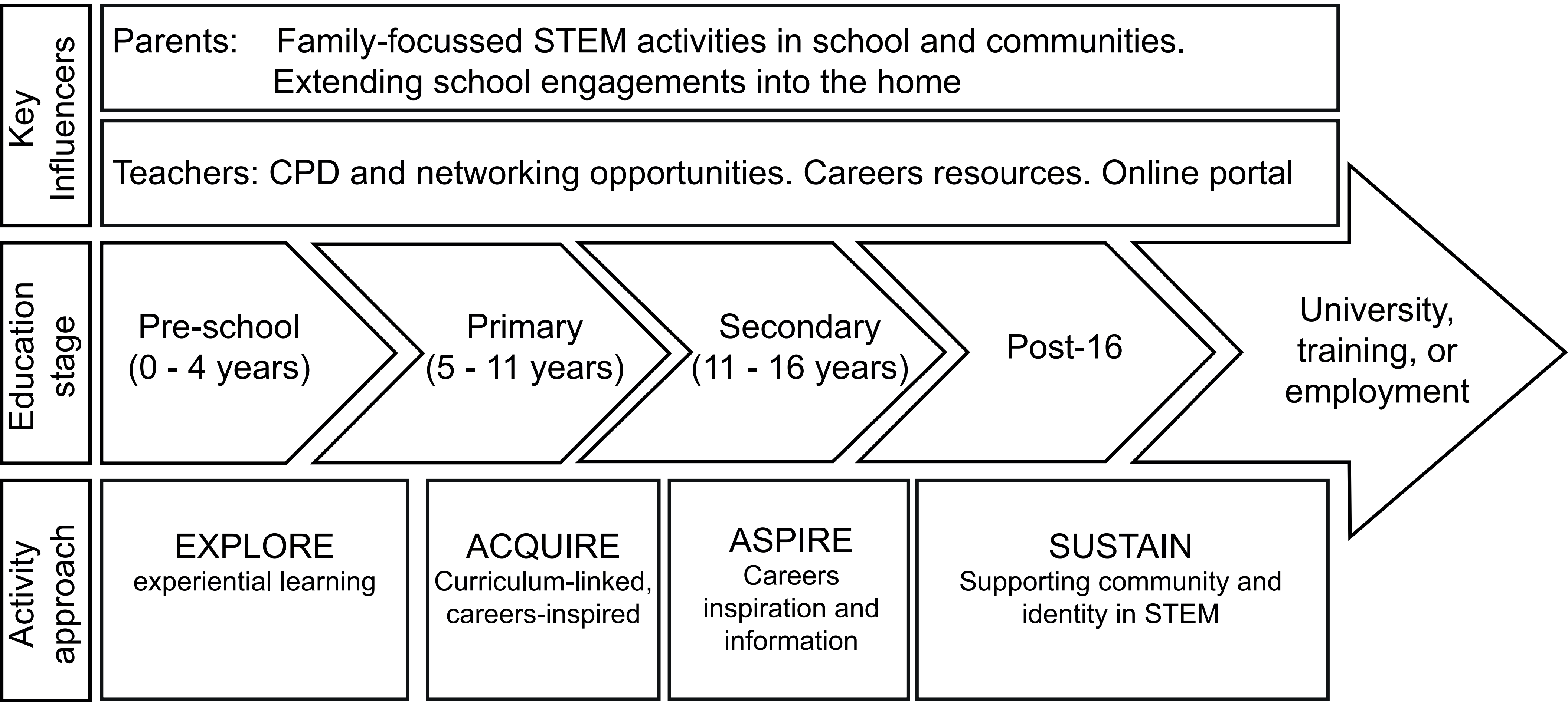
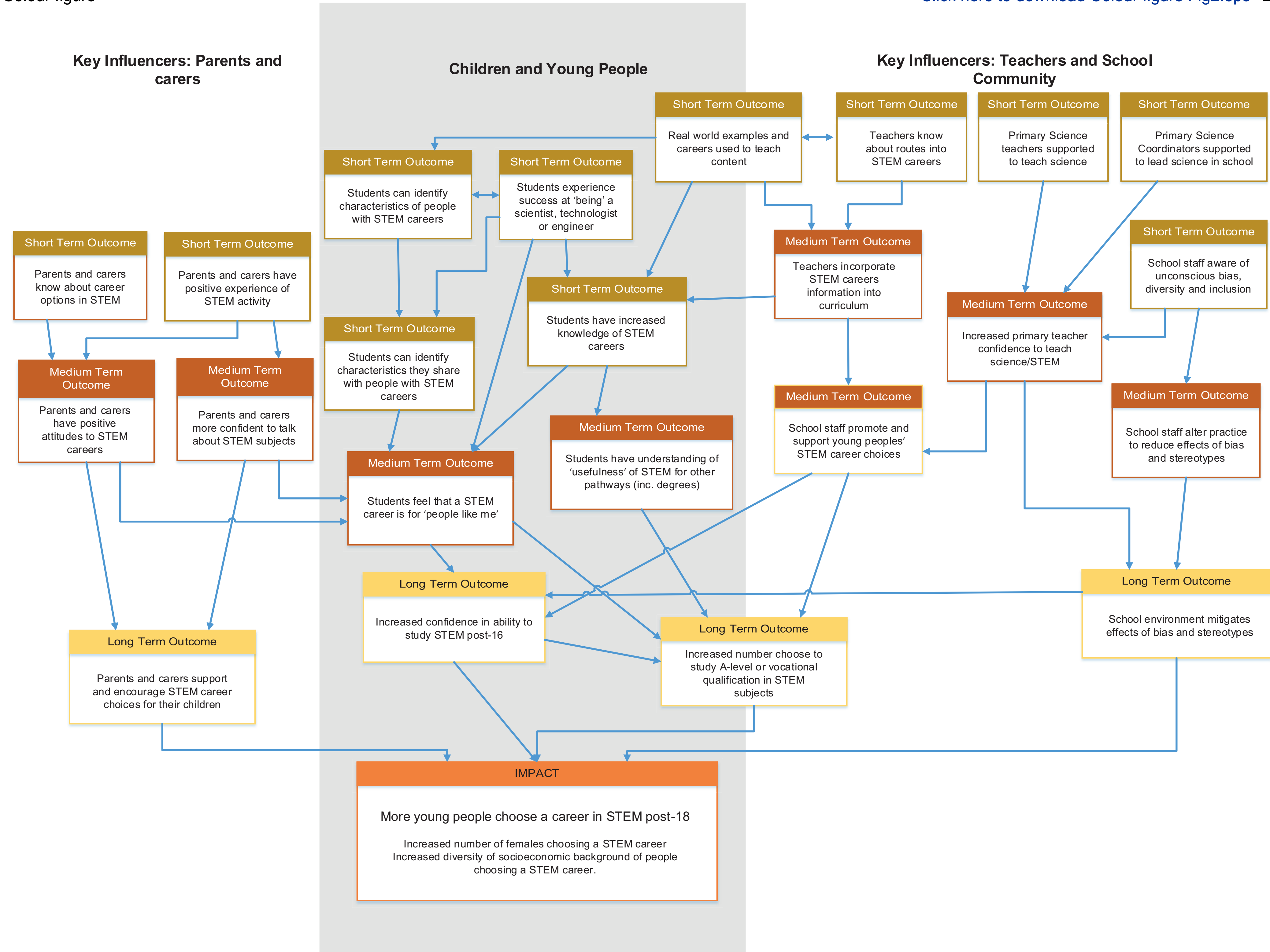
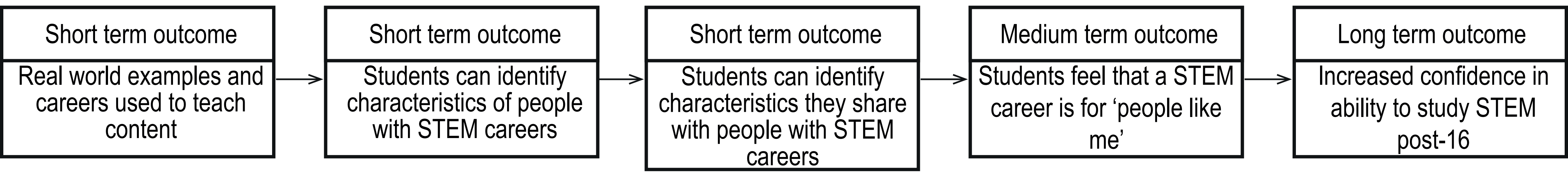

Key Influencers
Parents: Family-focussed STEM activities in school and communities. Extending school engagements into the home
Teachers: CPD and networking opportunities. Careers resources. Online portal
Education stage
Pre-school (0 - 4 years)
Primary (5 - 11 years)
Secondary (11 - 16 years)
Post-16
University, training, or employment
Activity approach
EXPLORE experiential learning
ACQUIRE Curriculum-linked, careers-inspired
ASPIRE Careers inspiration and information
SUSTAIN Supporting community and identity in STEM

Colour figure

Click here to download Colour figure Fig2.eps




Short term outcome
Real world examples and careers used to teach content
Short term outcome
Students can identify characteristics of people with STEM careers
Short term outcome
Students can identify characteristics they share with people with STEM careers
Medium term outcome
Students feel that a STEM career is for 'people like me'
Long term outcome
Increased confidence in ability to study STEM post-16

Table

Table 1: Case studies of different interventions linked to short- and medium-term outcomes from the ToC

Case study	Short-term or medium-term outcomes from ToC addressed by intervention	Brief Description
A practical approach to experiencing careers in the Digital Games Industry	• *Students experience success at 'being a scientist, technologist or engineer'* • *Real world examples and careers are used to teach content.*	The digital tech industry, including digital games, is a large contributor to the economy of the North East. A series of workshops were developed which would introduce careers in the digital games industry to young people (*real world examples and careers*), provide them with a 'lived experience' of designing digital games (*success at being a technologist*) and give them an appreciation of stereotypes in games, and how to ensure that games are inclusive. Over the space of five weeks, young people created their own digital game and evaluated those of their classmates. Halfway through the intervention, the research team analysed the young people's games in terms of gender diversity and found that the female students chose a wide variety of lead and other characters (males, females and non-human) whereas the male students chose mainly male characters. These findings were shared and discussed with the students and they were given the opportunity to change their characters, with the majority choosing to include a wider range of characters in terms of gender and diversity.
Imagining the Sun: Exploring the unseen through art and science	• *Students have understanding of 'usefulness' of physics, technology and engineering for other pathways (inc. degrees).*	The intervention consisted of a pair of workshops combining art (poetry or visual art) and science to explore the structure of the sun, solar physics and creativity (*understanding of the usefulness of physics*). Each workshop including discussions with solar physicists and artists about the Sun's structure, practical demonstrations of the electro-magnetic spectrum, and creation of art and poetry using pupils' knowledge and understanding of the solar science concepts introduced. The workshops with visual arts took place in both primary and secondary schools with the activities tailored to the age of the young people, and the workshops with poetry took place in secondary schools.
Present, past and future geography	• *Students experience success at 'being' a scientist, technologist or engineer* • *Students have increased knowledge of careers in STEM.* • *Students can identify characteristics they share with people with STEM careers*	Past, present and future geography was a series of four linked primary school workshops based on academic research centred around anthropogenic climate change. The workshops were aimed at developing their understanding of important environmental issues as well as addressing the Theory of Change outcomes. Some of the researchers who developed and delivered the workshops were originally from the North East region where the schools were based so pupils also had the opportunity *to identify characteristics (regional identity) that they shared with people with STEM careers (researchers).* The workshops focused on 4 careers-linked themes: Sea-level science and glaciology ("Present"), Palaeontology ("Past"), Environmental Modelling and Environmental Planning ("Future"). In each workshop there was a practical activity which allowed students to use skills that the researchers described as important for their career (*experience success at being a scientist*).
Bridging the gap: Exploring professional roles in construction and the built environment.	• *Students have increased knowledge of future careers in STEM* • *Students experience success at 'being' a scientist, technologist or engineer* • *Students can identify characteristics of people within STEM careers.*	This intervention was part of a wider local council initiative called 'Construction Week' and had a focus specifically on careers in construction and the built environment (*increased knowledge of future careers in STEM*). Students aged 14+ took part in three different activities over the course of a day. In the first activity students interacted with a mix of people who worked in a professional role within the sector, carefully chosen to represent a range of diverse backgrounds (*identify characteristics of people with STEM careers*). In the second activity, students were taken on a site visit to see a range of new and

		existing buildings to understand how construction works in practice and what are the different elements, processes and roles in designing, constructing and managing a building. Each tour was led by a professional or undergraduate student from the sector. In the final activity, students were asked to complete a Building Information Modelling (BIM) digital build activity giving them practical experience of the growing use of technology within the sector (*experience success at 'being' a technologist*). This case study shows that even single interventions can be planned using the Theory of Change to increase their effectiveness.
Pop-up shop outreach	• *Parents and carers know about career options in STEM* • *Parents and carers have positive experiences of STEM activity.* • *Primary science teachers supported to teach science* • *Teachers know about routes into STEM careers*	In order to interact with children and families in an out-of-school setting, the Outreach Project ran STEM Pop-Up Shops in local shopping centres three times a year during half-term holidays. Shopping centres were identified as being close to partner primary schools and in areas of deprivation. Careers-themed hands-on activities were developed for each Pop-Up Shop, and parents and children encouraged to work together to do the activities (*positive experience of STEM activity*). As part of the Pop-Up Shops, undergraduate students were trained to lead the different activities. These students were either studying for a STEM qualification, or training to be a primary teacher. This had a two-fold benefit: the presence of the STEM students allowed families to meet people with (beginning) STEM careers (*know about career options in STEM)* and the education students were able to develop their knowledge of science and STEM careers (*primary science teachers supported to teach science*; *teachers know about routes into STEM careers*).
Scientist of the Week	• *Students have increased knowledge of STEM careers* • *Students can identify characteristics they share with people with STEM careers* • *Real world examples and careers are used to teach content.*	This five week, teacher-led intervention presented five STEM role-models to primary school children through the use of presentation materials during science lessons and postcards to take home (*increased knowledge of careers in STEM*). Each postcard included one STEM role model, with a short description of their work and three personal character attributes that they felt was important in helping them to be successful at their job. During science lessons each week, as part of the normal teaching process, teachers identified pupils who were showing the same character attributes, or asked pupils to use those attributes as part of the lesson activity (*identify characteristics they share with people with STEM careers*). The intervention was designed to reduce stereotypical views of people working in STEM and increase positive attributes associated with them.
Primary Science Co-ordinators forum.	• *Primary science coordinators supported to lead science in school* • *Primary science teachers supported to teach science*	To support the long-term development of teacher confidence and science within primary schools, the Outreach Project led a primary science coordinators forum each half-term (*Primary science coordinators supported to lead science in school*). Primary science coordinators (who organise the subject within the primary school) came together as a professional learning community (the Primary Science Coordinators forum) to share ideas about both teaching and leading science, to hear about research that was relevant to their classroom practice, to try out new activities and equipment, and to shape the Outreach Project's future interactions with school. The forum allowed the coordinators to develop as leaders and equipped them to better support their colleagues in school to teach science (*primary science teachers supported to teach science*).

Supplementary Material S1

A review of literature underpinning the short-, medium- and long-term outcomes of the Theory of Change.

As described in "A Theory of Change for improving children's perceptions, aspirations and uptake of STEM careers" the identification of the short-, medium-, and long-term outcomes that make up the Theory of Change (ToC) was supported by a review of the literature relating to each stakeholder group and careers choice. This supplementary material provides additional references linked to the different outcomes, beyond those contained in the main paper. An understanding of this literature was also used to shape the nature of interventions used by the Outreach Project team.

Children and Young People

Many informal STEM education initiatives have been targeted at young people aged between 11-14 years old (Royal Academy of Engineering 2016). However, there have been recommendations to start careers outreach with children younger than 11 (HEFCE and OFFA 2013, ASPIRES 2013).

Much of the framing for interventions has been around the need to 'raise awareness and stimulate interest in STEM among children and young people' (House of Commons Science and Technology Committee 2017, 22). Bennet, Lubben and Hogarth (2007) found that context-based learning was beneficial in improving children's attitudes to science, and Reiss and Mujtaba (2017) identified that students were more likely to study physics or mathematics if they felt that this would help them in the future. For many children and young people, particularly girls, there is a 'lack of fit' between how they see themselves as a person and a student and their view of 'science' and 'scientists' (Archer et al. 2013; Archer et al. 2017). Macdonald (2014) recommends the use of characteristics to describe careers to allow easier identification of STEM careers as being for 'people like me'.

The framing of careers activities for different ages was explored by Howard and Walsh (2010) who described children's level of understanding of careers using the Conceptions of Career Choice and Attainment (CCCA) model which classifies children and young people's developing career choices into six levels dependent on their cognitive reasoning, which generally correlates with their age as shown in Table S1. The levels of CCCA progress from very general and unfocussed ideas about careers at Level 1, through to a sophisticated consideration of a wide range of factors that interact to support career attainment.

Level	Typical conception of careers
Level 1: Pure association	Job/career simply exists; gives a list of statements about job/career when asked to describe career choice.
Level 2: Magical Connection	No mechanism for career choice and attainment, they just happen.
Level 3: External Activities	Simple process of learning about jobs, choosing based on interests. Will give description of external, observable and learnable skills that lead to a career.
Level 4: Internal Processes and capacities	Start to match self to careers. Includes job/workplace activities or characteristics, personal interests and abilities. Recognise that attainment requires learning skills and having the ability to do the work.
Level 5: Interaction	Recognition that choice requires the consideration of interaction of personal attributes and environmental influences, with many possible outcomes. Attainment involves dynamic interaction of multiple factors at personal, relational, and immediate environmental levels.
Level 6: Systemic interaction	Understands that career choice needs to take into account the interaction of personal attributes, environmental influences, and systemic level factors (e.g. Labour market information). Attainment involves dynamic interactions of factors at the personal, relational, environmental and societal levels (e.g. emerging occupations).

Table S1: Summary of Conceptions of career choice and attainment model showing the developing understanding and reasoning around career choice adapted from (Howard and Walsh 2010)

Teacher influence at primary and secondary school

It is through teachers that pre-school and primary children are first introduced to science in a formal fashion. How well this is done will depend on the attitudes, confidence and levels of self-efficacy towards science of the primary school teachers (Van Aalderen-smeets, Walma Van Der Molen and Asma 2012).

Teachers' own experience of school science will affect their self-efficacy and confidence to teach different aspects of science (Brigido, Borrachero, Bermejo and Mellado 2013) and this, in turn, will affect the achievement and attitudes of the children they teach (Lumpe, Czerniak, Haney and Beltyukova 2012).

Andersson and Gullberg (2014) identify that teachers can support children to feel positive towards science by valuing their contributions and use questioning to encourage them to explore scientific concepts in an age-appropriate way. Fleer (2017) suggests that for teachers in primary schools with a limited science background, using questioning techniques also provides a way to teach science which draws on their professional knowledge and competences as educators rather than relying on subject knowledge.

Providing career advice:

Teachers may be ambivalent about providing careers information or guidance to pupils; recognising that they know their students' attainment and interests well, but also aware that they might not be able to give up-to-date guidance to students (Watermeyer, Morton and Collins 2016). To help teachers improve at this aspect of their role will require additional training. Cordingley et al. (2015) recommend that continuing professional development (CPD) should take place over an extended period of time to be most effective and professional learning communities (Jones, Gardner, Roberson and Robert 2013) can provide this extended CPD for teacher development.

Tackling teachers' gender-based unconscious biases has been shown to improve the uptake of physics A-levels amongst female students (Institute of Physics 2017).

Parents and carers

Evangelou et al. (2013, 128) describe parents as "their child's first and most important educators…" highlighting the important role of parents in supporting the development of children as learners before they start school. For this reason, See and Gorard (2013) identified pre-school and early primary school as the most promising phase for parental involvement.

Parents and families can exert considerable influence on the formation and further development of children's interests (Crowley and Jacobs 2002; Zimmerman, Perin and Bell 2010). Stake (2006) found that family encouragement of science was the strongest family-related predictor of positive science attitudes in young people. A family background where science is valued and included in everyday conversation makes science careers more 'thinkable' for young people (Archer et al. 2012).

As well as supporting attainment, parents and carers also strongly influence the development and direction of children's aspirations (Castro Exposito-Casas, Koehler, Harkness 2012). High levels of parental expectation and consistent encouragement have been shown to be positively associated with high aspirations and Higher Education enrolments in young people (Desforges and Abouchaar 2003) and parental interest and enthusiasm for education are important predictors of a child's future success in life (Blanden 2006). Aspirations start to develop early in a child's life and so supporting parents' aspirations for their children is beneficial (Gutman and Akerman 2008). However, it should also be recognised that structural inequalities may also shape parental decision making (Exley 2013) leading to different career choices for pupils in more or less deprived areas (Chambers, Kashefpakdel, Rehil and Percy 2018).

Beyond general educational aspirations, parental attitudes towards science affect children and young people's achievement in science (Archer et al. 2012), with the effect of a positive attitude being greater for families with a lower socio-economic background (Perera 2014). Parents who had poor experiences of science when they were at school (Kaya and Lundeen 2010) may have a lack of interest in providing science support. Alternatively, parents and carers may wish to help their children with science, but not feel confident enough to do so (EON 2016). Providing parents with positive hands-on experiences of science can help overcome lack of confidence and low self-efficacy and provide an impetus to greater involvement in their child's science learning (Kaya and Lundeen 2010; Shymansky, Hand and Yore 2000). In the UK, for family members whose highest qualification in science was obtained at the age of 16, there may be a view of science as a body of knowledge which is considered as fixed and mostly complete, rather than as a method of understanding the world (Carey and Smith 1993). This feeling that science is something that you should know the answers to can further reduce parents' self-confidence to support their children (EON 2016). Similarly, limited knowledge about careers in physics, engineering and technology entail may inhibit parents from discussing these careers with their children (Archer, DeWitt and Wong 2013).

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Supplementary Material, S2:

Assumptions, pre-requisites and barriers for the Theory of Change (ToC)

'ToC is not a sociological or psychological theory … but a pragmatic framework which describes how the intervention affects change.' (De Silva, et al. 2014, p.2 of 12).

In every ToC assumptions are made about the environment or situation that the intervention is taking place in. The pragmatic nature of ToC means that there will also be barriers that can prevent the final impact (goal) of the intervention being achieved. In this supplementary material the assumptions behind the ToC, the pre-requisites to its impact, and the barriers to its implementation are presented.

Assumptions:

(1) Children and young people like science (Wellcome Trust, 2013) and the activities developed by the Outreach Group are appealing to the different audiences and stakeholders.

(2) Children make career-limiting choices early (Gottfredson, 1983).

(3) Career decisions are made by children with influence and support from their families (Ikonen et al 2017)

(4) In terms of curriculum content, the focus of the activities is on science for primary aged children and physics, (digital) technology and engineering for older children to match the curriculum and the STEM sectors which have a particularly poor balance in terms of gender up to ages 18. Where STEM is used the focus is on physical sciences, (digital technology) and engineering, and not on biology/chemistry, although related careers (e.g. bioengineering, medical physicist) may be included.

(5) The number of boys choosing STEM careers does not decline from current levels. This implies that the approaches chosen are not ‘off-putting’ for this demographic.

(6) There is a supportive environment for under-represented groups in universities and in companies offering vocational routes.

(7) Industry responds to education-based diversity initiatives by making workplaces ‘people friendly’ for all employees. If workplaces are not welcoming to a diverse range of people (Casad et al. 2018) then even if the aim of the ToC is achieved and young people choose to study STEM, as they progress they may make a choice not to pursue the possibility of working in those sectors. They may feel that, regardless of what was said during interventions, those sectors are still ‘not for people like me’. Beyond simply being welcoming, STEM sectors need to change the predominantly masculine culture within them so that the possibility of entering into those sectors for women, and those from other underrepresented backgrounds, are able to consider themselves as people “who can legitimately “do” physics’ (Archer et al. 2017).

Pre-requisites:

(1) Students who take combined science are encouraged to study A-level sciences, and accepted onto the course by schools (Archer, Moote, Francis, DeWitt & Yeomans 2016).

(2) Schools/Colleges offer suitable STEM courses, or pupils can transfer to a setting that does (Doward 2017).

(3) The routes into STEM that are available to young people are also important, and there is a need to diversify the entry routes into STEM careers, particularly in the UK, and provide high quality apprenticeships or other non-graduate routes into technical roles in a wide variety of STEM sectors.

Barriers:

(1) Media stories, imagery and language highlighting persistence of gender discrimination in STEM workplaces.

(2) Lack of high-quality careers provision in schools.

(3) Schools do not promote non-traditional routes to all students.

(4) Lack of STEM teachers.

(5) Curriculum is too content heavy / uninteresting for pupils.

(6) Workload and accountability pressures for teachers and schools.

(7) Teachers perceive that unconscious bias training is about physics (or science) 'grabbing students'.

(8) Teachers do not see the need to change their practice, or are discouraged to do so by working practices in their school.

(9) Parents have had poor experience of science and maths in the past.

(10) Traditional gender norms held by parents (Archer, DeWitt, Osborne, Dillon Willis & Wong 2013) which means that they discourage children from pursuing norm-breaking careers..

(11) Parents see vocational routes as having lower status.

(12) External agencies find it difficult to engage with parents at secondary.

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