Innovative methods for evaluating the science capital of young children

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***Abstract* – Considerable effort has been spent on interventions to increase the numbers/diversity of young people studying Science, Technology, Engineering and Mathematics (STEM) and/or entering STEM related careers with little evidence of their effectiveness. In the UK, less than 10% of professional engineers are female. Science capital is a recent concept for capturing those elements that influence children's choice of a science-related career. Children with higher science capital are more likely to choose a STEM career than those with lower science capital and therefore interventions to increase science capital are needed. Initially studies evaluating science capital have focused on secondary age children (aged 11 – 18 years). Here a research approach for evaluating science capital among primary age children (aged 7 – 11 years) is presented using a mixed methods approach. Results indicate that children share similar perceptions of scientists as 'hardworking', 'clever' and 'creative' independent of gender, age and science capital. However, children's self-identify differed by gender, age and science capital, illustrating significant gaps for some children between their self-identity and that of a scientist. Interventions focusing on narrowing this gap should increase the likelihood of them considering a science-related career.**

Keywords—science education; science capital; STEM outreach; research methods; career advice and guidance; young people; gender; diversity.

I. Introduction

The shortage of young people in the UK choosing to follow Science, Technology, Engineering and Mathematics (STEM) pathways from school to further and higher education and beyond is widely acknowledged and there are similar challenges elsewhere in Europe and North America [1] [2] [3]. To address this, the UK government and relevant funding bodies have invested heavily, establishing and supporting a plethora of regional and national STEM interventions. While the numbers of students choosing STEM has slowly increased, there still remains a strong gender imbalance in physics, computer science and engineering [4]. In 2014, only 14% of Engineering and Technology undergraduate students, 17% of Computer Science undergraduate students and 21% of Physics undergraduate students were female [4].

For change to be realized, greater clarity is needed about what does and does not 'work' with STEM interventions. However, interventions are often under or misevaluated, struggle to validate their effectiveness, or do not share their findings widely [5]. Interventions commonly struggle to find appropriate and practicable evaluation methods and many evaluations lack the resources for longer term follow up [5]. Moreover, despite recommendations that STEM interventions need to target children at a younger age if they are to have an impact [6], few interventions are working with primary age children and even fewer are publishing their evaluation methods and instruments. Barriers to evaluation can be greater with younger children, compounded with difficulties in identifying suitable measures and appropriate instruments [7].

These challenges were faced when considering the evaluation of the impact of Think Physics, a regional STEM initiative, on the science attitudes and aspirations of the project's younger participants, children aged 3 – 11. Drawing on the concept of 'science capital', a theory and framework developed by the ASPIRES and ASPIRES 2 projects for addressing and influencing science participation and engagement [8], a set of innovative research instruments to identify and evaluate 'science capital' in younger children (aged 7-11 years) has been developed. The research instruments are sufficiently complex to provide a useful set of qualitative and quantitative data, while also being sufficiently stimulating and straight-forward for use with younger children. These instruments could be adapted for use in the evaluation of other science, engineering and computer science interventions across a similar age range of children.

II. Background

Think Physics is a collaborative STEM initiative at Northumbria University, Newcastle, working with young people and their support networks across the North East of England. Through collaboration with industry, science and education bodies and schools, Think Physics tackles the gender imbalance and under-representation of low socio-economic groups in the physics, engineering and computer science sectors. Working with 30 local partner schools, 14 primary schools (teaching children aged 4-11) and 16 secondary (teaching children aged 11-16+), the project provides sustained engagement and gender neutral support to children and their teachers throughout their education journey. The project has a strong ethos that early interventions are key to developing and encouraging children's future attitudes and aspirations for careers using science.

A key objective of Think Physics is to build science capital in young people across the North East of England through a variety of interventions at school and in the wider community [9]. Science capital, applies Bourdieu's concepts of social capital and cultural capital within a scientific context [10]. ASPIRES defines science capital as a person's, "science-related qualifications, understanding, knowledge (about science and 'how it works'), interest and social contacts (e.g. knowing someone who works in a science-related job)" [8]. As with social and cultural capital, science capital affects how a person negotiates life and makes decisions. It can also reproduce inequalities in society. ASPIRES found that children with higher levels of science capital in their family were more likely to aspire towards a science-related career, than children with lower levels of science capital [8].

Think Physics required a set of research instruments to allow evaluation of science capital, based on identification and measurement of a child's perception of scientists, their science self-concept, and their aspiration towards STEM careers. A literature review revealed that instruments used to measure children's attitudes have traditionally been diverse in nature, including quantitative methods such as enrolment data, rating scales, interest inventories and preference ranking, and qualitative methods including interviews, classroom observations, interpretation of drawings and word association [7] [11] [12]. Studies have largely focused on assessing the attitudes of secondary age children (11-16+), although there has been a growing interest in the attitudes of primary children stemming from the introduction of science as a core subject in the UK's primary schools from 1989 [13]. However, Kerr and Murphy's literature review of instruments used to measure attitudes towards science in primary school children found that many of those used in these studies were not appropriate for, or regularly used with, children of this age [7]. The Draw a Scientist (DAST) model [14] has been widely used with children to study their perceptions of scientists, and has emerged as a research instrument for use with a variety of audiences, regardless of age, race or gender [15]. However, the Think Physics research team felt the model had limited use for this study. Whilst the DAST model may be useful in identifying perceptions of scientists, it does not provide an easy route to measure changes in perception over time. Additionally, researchers were keen to explore how children's perceptions of scientists correlated with their own science self-concept, and this lies outside the DAST model.

Researchers working with young children are challenged with ensuring the data collection process is enjoyable and appropriate for children, while at the same time maximizing the robustness and utility of the data collected [16]. Visual stimuli and creative methods can be particularly useful in research with younger children, as it can make the issue far more concrete than verbal representative alone. The National Children's Bureau in the UK recommends that data collection sessions last no longer than one hour, and include a variety of different activities to keep children engaged [17].

III. A Child-centered approach

The development of the research instruments was approached from a child-centered perspective, understanding children are similar to adults but with different competencies. Research with children thus requires researchers to adapt existing methods and develop innovative methods to meet children's skills and needs [16], with particular attention paid to language use, literacy and different stages of cognitive development [17]. Consideration was given to how the questions and topics in the ASPIRES quantitative self-completion survey could be adapted for use with younger children, aged 7-11. Self-completed questionnaires are generally unsuitable for children under 12 without adaptation [18], and so the questionnaire was simplified to nine key questions based primarily on the child's family background. This was complemented with practical sorting activities to gather information about science self-concept, perception of scientists and STEM aspirations.

In examining a variety of instruments, consideration was given to the type of pedagogical activities already used with children of this age. The Diamond 9 or diamond ranking, is a tool commonly used within the classroom to explore and clarify a child's value positions, thoughts and feelings on a particular topic. The activity is emerging as an instrument of participatory research with children and young people, and is often used in conjunction with other research instruments [19] [20]. The Diamond 9 is a sorting activity that asks children to rank pre-written statements, images or objects within a diamond formation. The strength of the instrument is that in asking people to rank items, and discuss their ranking decisions, they reveal the over-arching relationships by which they organize knowledge and make their understandings available for examination and comparison [19]. After exploring the range of existing instruments, the multi-disciplinary research team decided to adopt a mix of practical activities, including the Diamond 9, and a short survey for the evaluation of science capital in primary children.

The research instruments were developed and piloted with children to ensure that they were appropriate and understandable for the target age group. As two of the research instruments were based on a word card sorting exercise, it was critical to ensure the language used on these cards were appropriate for the target age range of children. The research team worked with 6 mixed education classes of children from the target age group to select the words used in the instruments.

These children were asked to answer the following questions:

- What six words would you use to describe yourself?
- What six words would you use to describe a scientist?
- What jobs do you know the names of?
- What would you like to be when you grow up?

These questions generated a pool of words from which those used in the instruments were selected. For the Diamond 9 (see *Figure.1*), answers to the first two questions were grouped, cross-referenced and nine of the attributes with high frequencies in both lists were selected. For the careers instrument, words from the list of jobs that children knew were selected, ensuring that they included jobs from a cross-section of society and STEM jobs. The research instruments were piloted and revised to ensure they were meaningful and appropriate for the target age groups.

IV. Research methods and instruments

While quantitative and survey studies are vital for research concerning children, there is a growing awareness that they cannot on their own capture all of the information and insight required to understand children's attitudes and experiences. A mixed methods approach to researching children's attitude is valuable, as it does not merely duplicate data but offers complementary insights and new ways of seeing that may be difficult to access through one method of data collection alone [21]. Kerr and Murphy [7] recommend that researchers incorporate a variety of qualitative and quantitative instruments in their research designs with children, because when given the opportunity to discuss any aspect of science using a variety of methods, a wealth of different and unpredicted viewpoints become apparent.

This study gathered data from over 450 children in Year 3 (age 7-8) and Year 5 (age 9-10) of seven co-education primary schools in the North of England. Sampling was requested for the full year group and all children present in class on the day were sampled. The final sample for analysis was 350 children, for whom a complete dataset was available. No children or their parents opted out of the research activities in advance or on the day of data collection. Follow up data collection will occur two years after the initial data collection, and data will be collected from the same year groups in the same schools using the same instruments. This will allow measurement of changes to children's science capital, science self-concept and STEM career aspirations over time, and evaluate the impact of the Think Physics project in these areas.

Additionally, convenience sampling was collected from 11 children aged 7-11, related to academic staff in the Faculty of Engineering and Environment at Northumbria University, and therefore believed to have 'high science capital'. This group was sampled to give an idea of what high science capital may look like when measured using the research instruments. Further sampling is required before assumptions about the attitudes of 'high science capital' children can be made.

The set of research instruments comprises:

- A short questionnaire
- A Diamond 9 based sorting activity about attributes – Most Like Me/Most Like a Scientist
- A sorting activity about STEM jobs

To allow collection and analyses of pupil-level data across the activities, children were allocated a number, and this number was then associated with the data for each child. A photograph was taken of the child's responses to activities.

A. *Questionnaire: Family background and interest in science*

The questionnaire gathers information about a child's family background and their interest in science and provides the variables for analysis of the instruments below. The language and concepts of the ASPIRES questionnaire were simplified. The Likert scales were adapted from a word based approach to a pictorial approach, utilizing smiley faces. To avoid literacy issues, the questions were read aloud for all children to complete at the same time. The research team also ensured that each child had completed the question before moving to the next.

B. *Diamond Ranking: Most like me/Most like a scientist*

Children were given nine cards featuring different character traits: *clever, cool, creative, kind, friendly, fun, hard-working, sensible* and *strange*. Firstly, children ranked the words into a diamond formation, with 'most like me' at the top and 'least like me' at the bottom. Secondly, children sort the same words into a different diamond formation with 'Most like a scientist' at the top and 'Least like a scientist' at the bottom (see *Figure.1*).

C. *Sorting Activity: STEM Jobs*

Children were given 30 cards, each with a job printed on it. Each word was read aloud to the children, but was not explained. The children then put each job into one of two circles on a sheet of paper labelled 'Jobs I know' and 'Jobs I don't know'. This takes into account the different starting points of knowledge. At the end of the activity, all cards in the 'Jobs I know' circle are selected for use in the next exercise, where children sort these cards into circles labelled: 'Would like to do', 'Would not like to do' and 'Not sure'.

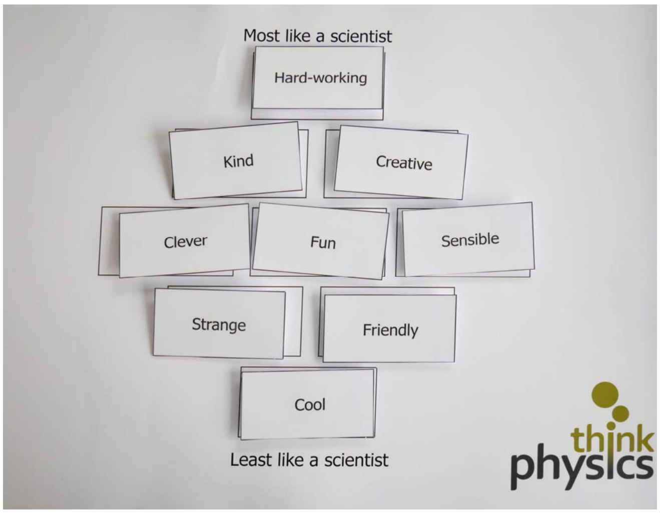

Fig. 1. Most Like a Scientist/Least Like a Scientist Instrument

V. Analysis and Results

Data was collected from 350 children in seven primary schools and from 11 other children believed to have high science capital. The questionnaire and photographic data were coded for analysis. Initial frequency analysis was conducted for the Diamond 9: Most like Me/Most like a Scientist instrument using gender and age variables from the questionnaire. This section focuses on the analysis and results from the Diamond 9: Most Like Me/Most Like a Scientist instrument.

The position of each word in the top and bottom three positions of the diamond was tabulated, and a percentage appearance calculated. Words ranked in the middle row of the diamond were discarded for the purposes of the analysis.

A. Children's Perceptions of Scientists

The data showed that young children's perceptions of scientists are consistent when considered by gender, age and these two variables combined. 71% of all children rank *hardworking* as one of the top three positions of the 'Most like a scientist' diamond, followed by *clever* (69%) and *creative* (55%). The ranking of these three words is consistent when analysed by gender, age and these variables combined. Children rank *strange* (71%), *cool* (66%), and *fun* (52%) in the bottom three positions of the diamond. Ranking of these three words is again consistent when analysed by gender, age and these variables combined.

The data from the 'High Science Capital' group showed these children share the perceptions of scientists with sample population, with similar percentages for each characteristic.

B. Children's Self-Perception

Friendly was ranked in one of the top 'most like me' position of the diamond by 48% of all children, and appears with the highest or second highest frequency when analysed by gender, age and these variables combined. *Friendly* receives consistently low scores in the bottom three spaces of the diamond, when analysed by gender, age and these variables combined.

However, children's self-perceptions of other attributes were not consistent when analysed by gender and age. Boys were more likely to identify as *cool* and *clever*, and girls as *hardworking* and *kind*. *Hardworking* appears in the top three rankings 41% of the time for girls, and only 28% of the time for boys and *kind* appears in the top three rankings 40% of the time for girls, and 31% of the time for boys. *Cool* appears in the top three rankings 41% of the time for boys, and only 25% of the time for girls. *Clever* appears in the top three rankings 40% of the time for boys, and only 23% of the time for girls. The data also show that in some cases self-perceptions change with age. While *hardworking* is the highest ranking 'most like me' attribute for year 3 girls (age 7-8), it drops down to the fourth most commonly appearing attribute with year 5 girls (age 9-10).

Although in the initial development phase of the research instruments a number of children self-identified as s*trange*, this was not the case for these data. 76% of all children ranked *strange* in one of the bottom three positions of the diamond, and this perception is consistent when analysed by age, gender and these variables combined.

Interestingly, 'high science capital' groups' self-perception is much closer to that of their perceptions of scientists. They are much more likely to consider themselves *hardworking* (64%), *clever* (46%) and *sensible* (46%) than the whole sample population (35%, 30% and 27% respectively). They are also much less likely to consider themselves *friendly* (6%) and *fun* (6%) than the whole sample population (48% and 40% respectively). Due to the low numbers in the high science capital sample, further analysis by gender and age was not possible.

VI. Conclusions and Next Steps

These data show that children's perceptions of scientists remain consistent when analysed by gender and age, whereas children's self-perception differs when analysed by these variables. Young children tend to view scientists as 'hardworking' and 'clever'. However, they do not see scientists as 'strange' and this is counter to the popular stereotype of scientists.

The lower percentage of girls self-identifying as clever at age 7-10 is a concern, and will be a future area of research focus. To tackle the strong gender imbalance in the physics, computer science and engineering areas, it is important to narrow the gap between girls' self-perceptions and perceptions of scientists, so they can see STEM as offering careers for 'people like me' [22] [23]. The study hints that children with 'high science capital' tend to have less of a difference between their self-perception and their perception of scientists; however, a larger sample is required to explore this further.

Further development of the research instruments is planned to allow the data to be analysed statistically. Focus groups in additional partner schools will be carried out to explore emerging themes from the findings and the research team also plan additional data collection to explore whether location, and group dynamics influences the attitudes and aspirations collected from children using these instruments.

The research instruments will be used again in two years' time in the same schools to evaluate changes in the science capital of the children over a two-year period. This will allow evaluation of the effectiveness of Think Physics in building science capital, and supporting more children - particularly girls - to see science as something for 'people like me'.

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