LITERATURE REVIEW

DELIVERABLE N.2.1

OUR SPACE
OUR FUTURE

DELIVERABLE DESCRIPTION

This review examines published papers and project reports to provide a theoretical background and evidence base that can inform the development, delivery and evaluation of *Our Space Our Future*. The primary aim of this study is to explore the practices and approaches that involve, excite and empower school-aged students to feel space sciences are relevant to them. This review will:

1. Collate and summarise existing programmes into an accessible review.
2. Provide clear communication of the successes and challenges of these space science / STEM education and outreach initiatives and further links to best practice.

To be quoted as:
Leverment, S., Pennington, C. and Bartlett, S. (2019) "What practices truly involve, excite and empower school-aged students to feel space sciences are relevant to them: a systematic review of primary literature for the 'Our Space Our Future' project."

Deliverable:	D2.1 Literature Review
Work Package:	2
Due of Deliverable:	**Month 5**
Lead beneficiary of this deliverable:	**Explorer Dome**
Version:	**2**
Author(s) and Institution(s):	**Shaaron Leverment, Explorer Dome**
Submission Date:	31st March 2020
Reviewers:	**Wendy Sadler, Cardiff University. Lisbeth Walakira, Planetarium.**

Project co-funded by the European Commission within the H2020 Programme (2014-2020)		
PU	Public	**x**
CO	Confidential, only for members of the consortium (including the Commission Services)	
CI	Classified, as referred to in Commission Decision 2001/844/EC	

"This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821871"

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SUMMARY

Our Space Our Future is in the process of developing interventions for school-age children, their teachers and wider families. The aim is to take an evidence-informed approach to the good practice known and reported on across the sector, defined within project reports and evidenced in published papers. *Our Space Our Future* can then attempt to bridge the current gap between 'interest' in space science, and a growing 'identity' with space science, to encourage confidence and future aspirations for studying science subjects and considering space-related careers.

Twenty-four primary research papers and reports which fit the inclusion and exclusion criteria were obtained from 234 collected articles. These papers were put through a critical review performed independently by two reviewers. Nineteen project reports and published papers were taken forward as the research studies in the final analysis.

Pulling from these primary research studies, this systematic review takes a narrative structure to draw out the predominant themes to explore practices or approaches that nurture a student's personal identity with science.

Seven key recommendations were distilled from the 19 included articles. These recommendations are drawn from the themes that emerged across the varied literature, explored in full in the discussion section. Such recommendations are proposed in the conclusion as foundations for the ongoing development of *Our Space Our Future*.

This review concludes that *Our Space Our Future* should:

1. Get hands-on with real science skills
2. Not 'design for' or 'do to', but 'work with'
3. Celebrate success and bring in the wider family and community
4. Keep it careers-focused
5. Challenge unconscious bias
6. Bring a whole-school approach to our engagement
7. Build in legacy

Links to relevant research and current aligned programmes of work are provided alongside the limitations of this study.

1. TITLE

What practices truly involve, excite and empower school-aged students to feel space sciences are relevant to them?: a systematic review of primary literature for the *'Our Space Our Future'* project.

2. INTRODUCTION

Rationale

The vision of *Our Space Our Future* is based on the positive effects of STEM choices for young people. Alongside a growing demand for relevant skills and qualifications from a strong European space industry[1], there are current geographic STEM skill shortages, skill mismatches and bottlenecks across Europe[2,3]. The benefits of skills in STEM and space science are clear for future employment, technological progress and economic growth, as well as wider benefits of transferable skills, knowledge, curiosity and scientific literacy for individuals, culture and society[4,5].

However, research suggests that simply making science exciting and interesting is not the key to encouraging more students to consider science as an aspirational career[6]. Children can report that they find science fun, exciting, important and interesting, but this identity is 'doing' science rather than 'being' a scientist[7]. A recent survey of over 8000 school-aged students from 11 European countries found that enthusiasm from young people for space science was clear. Interest was shown for the subject matter and the field of space science was perceived as diverse and dynamic. However, yet again, these positive attitudes and perceptions did not translate into the same level of interest in pursuing a career in space science[8].

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[1] The Case for Space: The impact of space on the UK economy (2015) http://bit.ly/1Prul6m
[2] Does the EU need more STEM graduates? Final Report (2015) http://bit.ly/2CqXIpp
[3] EU Skills Panorama 2014: Focus on STEM skills (2014) https://bit.ly/2D5Ia9i
[4] IAU Astronomy for Development: Strategic Plan 2010-2020 (2012) http://bit.ly/2osZddk
[5] Walker, I. & Zhu, Y. (2013) 'The Benefit of STEM Skills to Individuals, Society, and the Economy: Report to Royal Society's Vision for Science and Mathematics'. (2013) http://bit.ly/2FzV9jr
[6] Archer, L. et al. (2013) 'Aspires: Young people's science and career aspirations, age 10-14'.https://bit.ly/2DPCnFl
[7] Archer, L. et al (2010) '"Doing" Science versus "Being" a Scientist: Examining 10/11-year-old School children's Constructions of Science through the Lens of Identity'. https://bit.ly/2GuI78R
[8] DeWitt, J. & Bultitude, K. (2018); Space Science: the View from European School Students'. https://bit.ly/2XrMSFT

Despite being backed by the economic case, the creative case, the social mobility and the social justice case for greater diversity in STEM, we have known for a while that our efforts in STEM education and engagement have been, unconsciously or consciously, excluding sections of society, and careers education is not reaching those who need it most[9].

"The gender, socio-economic and ethnic inequalities in STEM participation are deep seated. They are not simply the product of individual preferences but are profoundly influenced by social norms and processes." [10]

For children and young people experiencing disadvantage, engaging with science can and does make a difference in young people's lives, including positive outcomes such as increased self-belief, enhanced essential skills and feeling positively empowered[11].

It is maintained that collaboration between teachers and practitioners is essential for STEM outreach to be successful and to ensure that the right students are targeted and activities are complementary to school activities[12]. When practitioners often report that they repeatedly engage with the same group of schools - schools with pro-active teachers, with high achieving students predisposed to positive attitudes to science - the need to ensure that science is more accessible for a broader range of schools and students is an important, and ongoing, conversation for the formal and informal STEM education sectors.

Addressing these social inequities is central to *Our Space Our Future* as we develop interventions in schools that support bridging the gap between 'excitement' and 'interest' in space science and shifting perceptions around space science and space careers towards a growing identity, perception of self-relevance and 'something for me'.

Research Aims

The foundation of the *Our Space Our Future* programme of work is to take an evidence-informed standpoint, creating a toolkit and programme of delivery and evaluation that is rooted in research and builds from sector-wide best practice.

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[9] Archer, L & Moote, J. (2016) 'ASPIRES 2 Project Spotlight: Year 11 Students' Views of Careers Education and Work Experience'. https://bit.ly/2GTO3c2

[10] What influences participation in science and mathematics?' A briefing paper from the Targeted Initiative on Science and Mathematics Education (TISME) (2013) https://bit.ly/2VcV9QE

[11] The role of informal science in youth work: findings from Curiosity round one (2019) https://bit.ly/2ZrL0Px

[12] Aslam, F., Adefila, A. & Bagiya, Y. (2018) 'STEM outreach activities: an approach to teachers' professional development'. https://bit.ly/2J01AjK

The vision of *Our Space Our Future* is a society that enables and empowers all students (regardless of gender, ethnicity, language, culture, belief, sexuality, disability or socio-economic background) to consider a career related to space science as a relevant, attainable and exciting aspiration for their future.

The primary aim of this review is to provide an evidence base for this vision, by collating the practices and approaches explored in previously documented programmes, that involve, excite and empower school-aged students to feel STEM and space sciences are relevant for them.

There is a strong evidence base investigating attitudes, perceptions, interests and aspirations of school-aged students. This review links to this body of research but is also concerned with examining published papers and project reports that explore specific interventions with school-aged children, teachers or families. This broader approach is taken in order to:

1. Collate and summarise existing programmes into an accessible review.
2. Provide clear communication of the successes and challenges of these space science / STEM education and outreach interventions, to guide the development of *Our Space Our Future* procedures.

3. METHOD

Search Strategy

The aims of this study were met by conducting a mixed-method review of the current literature. In order to capture completed, current and new initiatives, project reports were included alongside published literature. Literature was identified through all *Our Space Our Future* consortium partners, providing a relevant European base for the research. Consortium partners submitted papers, reports and programmes that influence their current practice, thus providing access to the evidence base that informs changes in approach for experienced space science educators in centres of excellence from across Europe.

Additional snowball search strategies included reference searching these sector-influencing papers to obtain a wider evidence base of primary research. Conference presentations, posters or abstracts submitted were followed up with extensive online search and, in some instances, direct contact with the authors to obtain full-text material for inclusion where it was available.

Full university electronic databases were not accessible at the time of the search. Therefore, the electronic search strategy included utilising the search engine 'Google Scholar' and the web portal 'informalscience.org' to access recent space-related education project reports and publications with the following search terms:

- 'space outreach intervention'
- 'STEM space outreach'
- 'STEM OR space engagement' (informalscience.org)
- 'inclusion and diversity' (informalscience.org)

Ethics Protocol

This study is of secondary data and does not use human participants, however full ethical approval was obtained from Cardiff University before undertaking this review.
Included studies were searched to ascertain whether the study participants gave voluntary informed consent and this contributed to the quality analysis of the paper.

Anonymity and confidentially of all participants in included studies were upheld and no personal information that identified participants is discussed in this review. The reviewers were mindful of duplicated data, suspect fraudulent studies or plagiarised research during critical analysis, and this review is transparent in its discussion of bias and states any conflict of interest.

Eligibility Criteria

Full-text versions of all relevant papers were obtained. Titles, abstracts and methodologies were read and articles selected according to the criteria stated below:

Inclusion Criteria

1. The article is from a published paper or a project report.
2. The article is a primary research study.
3. The study investigates the impact of a specific intervention (such as a practice, approach, or event/series of events).
4. The study investigates the impact on our target audience (school-aged children, teachers or public/family participants).

Exclusion Criteria

1. The article is a review or meta-analysis, or an essay, letter, conference poster, abstract, website article, blog (etc.) that is not supported by full-text articles describing methodology and evaluation in sufficient detail.
2. The article is primary research but irrelevant to the research question.
3. The article is primary research but does not involve a method that is replicable by *Our Space Our Future* delivery partners.
4. The article includes a secondary analysis of data previously included for the review.

Published papers and project reports that adhered to all inclusion and exclusion criteria were critically appraised using a system, based on the CASP checklist tools available under creative commons license at http://www.casp-uk.net. This was in order to examine the validity and reliability of results.

Critical appraisal was independently performed by two reviewers with a strong inter-rater agreement ($\kappa = 0.9$). Questions addressed during critical appraisal can be found in Appendix I-III.

Data Synthesis

A lack of consistency across questionnaires and questionnaire items prevented meaningful meta-analysis of raw data. Therefore, data synthesis takes a narrative structure to draw conclusions and involves recording descriptive information about the participants, methodology, intervention and impact.

To guide the approach and practices for *Our Space Our Future*, we pull together the repeating practice themes that emerge across multiple studies and link with wider research in the area.

4. RESULTS

Study Selection

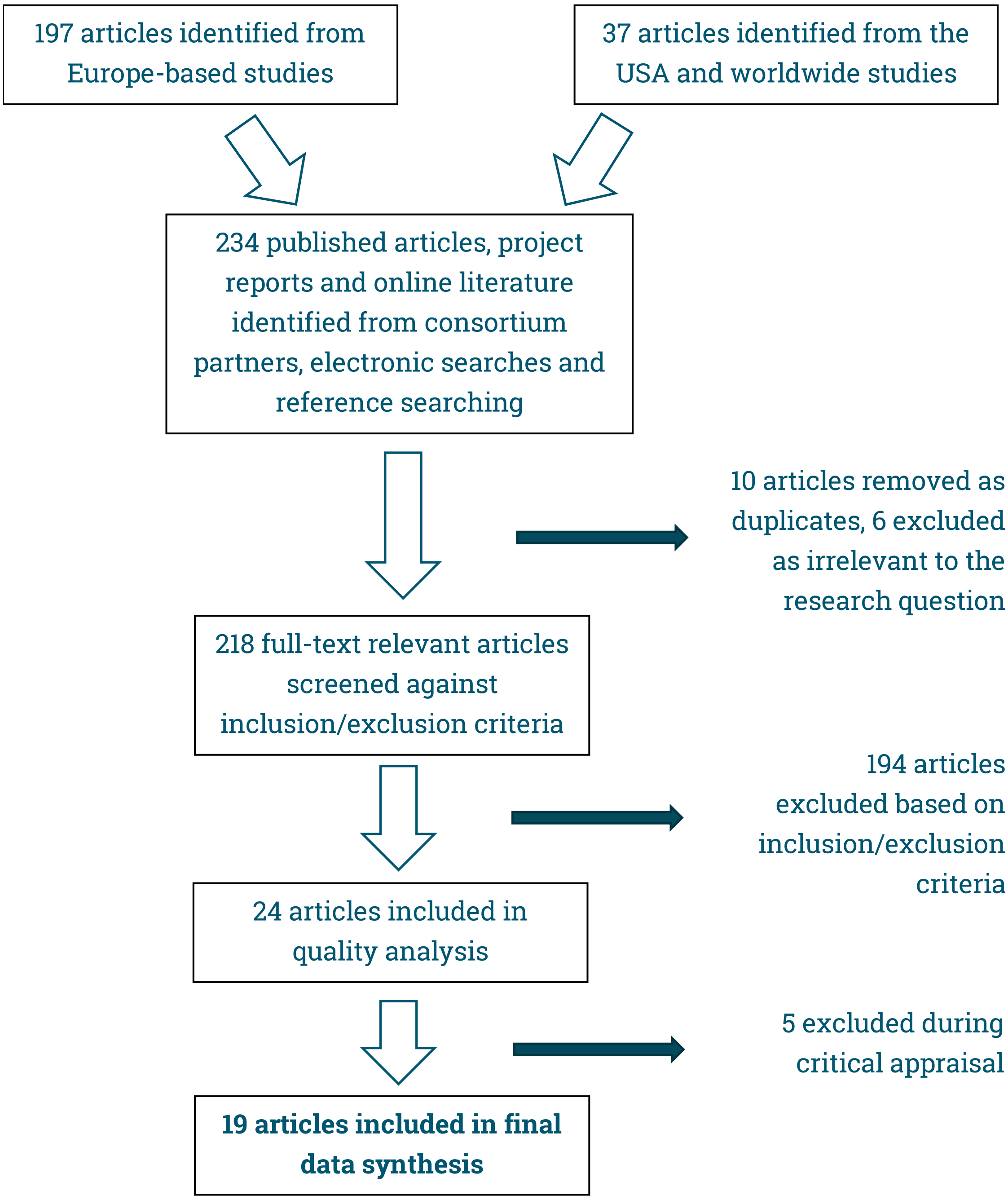


Figure 1
Search results detailing the number of studies identified, screend, assessed and included in the final review

Study Characteristics

Table 1

A summary of study design and impacts measured within 19 included studies

Study N°	Title	Year	Project Report or Published Pater	Primary Audience For the intervention	Numbers of participants in overall study	Cohort, case control RCT or Case study	Single or Multiple interventions	Measures
1	Implicit Theories of Intelligence Predict Achievement Across an Adolescent Transition: A Longitudinal Study and an Intervention	2007	Published Paper	School- students (aged 12-13)	91	RCT	Multiple (8 x 25mins, 1/week)	Longitudinal Maths grade achievements (baseline and outcome), Theory of intelligence and motivational variables (student questionnaire and teacher assessment)
2	Confirming the legitimacy of female participation in STEM	2012	Published Paper	Female students (aged 12-14) and parents	71 students + 65 parents (+ 21 in observations)	Cohort	Multiple (8 Saturday science club)	Cross sectional questionnaires collected over 3 years (2008-2010) + Observational data from 2010
3	EU-UNAWE ITALY	2013	Project Report & Evaluation Presentation	Teachers, school- children (aged 4-11) & parents	400 teachers 5600 children (National programme)	School case studies	Multiple (case study illustrates 5 sessions with one school)	Longitudinal analysis of the percentage of 'scientifically correct' answers (baseline and outcome), attention (nursery), measures of teacher/children/parent curiosity and intercultural learning
4	The Blue Marble: a model for primary school STEM outreach		Published Paper	School children (aged 6-11)	349	Cohort	Single (day long)	Questionnaires (pre & post intervention). Items to measure interest, enjoyment and changing attitudes towards science
5	Smarter UK		Independent Project Evaluation	School students (aged 13-16)	Approx. 9000 (National programme)	Cohort	Single (60-90 minutes)	Cross Sectional analysis, questionnaires, observations + teacher assessments. Measuring engagement, effectiveness of format, usefulness for teachers and impact on neuroscience researchers

Study N°	Title	Year	Project Report or Published Pater	Primary Audience For the intervention	Numbers of participants in overall study	Cohort, case control RCT or Case study	Single or Multiple interventions	Measures
6	A Large-Scale Inquiry-Based Astronomy Intervention Project: Impact on Students' Content Knowledge Performance and Views of their High School Science Classroom	2015	Published Paper	Teachers	Approx. 26 teachers	Cohort	Single (3-4 days training) (NB some teachers from round 1 also attended round 2)	Quantitative study evaluating students of teachers (baseline and outcome): 'Astronomy Knowledge Questionnaire': content knowledge gains and 'Secondary School Science Questionnaire': student views of school science
7	Teachers' Understanding and Operationalisation of 'Science Capital'	2015	Published Paper	Teachers (teaching science to pupils aged 11-14)	10 teachers	Cohort	Multiple (1x full-day + 7x twilight) sessions over 12 months.	Qualitative case study approach (interview & classroom observations) to measure understanding and operationalising of science capital concepts into classroom practice
8	Thinking, Doing, Talking Science	2015	Independent Project Evaluation Report	Teachers (teaching students aged 9-10)	42 schools	RCT	Multiple (5 x inset + additional days) over 6 months	Longitudinal evaluation of student outcomes, Measuring science attainment, attitudes towards science, confidence in teaching science and changes in practice
9	Paired Peer Learning through Engineering Education Outreach	2016	Published Paper	10 Pre-service teachers and 11 student Engineers	Focus on impact on teachers (but outreach to 269 children)	Cohort	Multiple (training + planning + delivery meetings)	Longitudinal study investigated teachers' confidence and self-efficacy and value of active-learning
10	The Makerspace Movement: Sites of Possibilities for Equitable Opportunities to Engage Underrepresented Youth in STEM	2017	Published Paper	School-aged students (aged 10-14)	36 11 participated for 2 years (2013–2015) 25 participated for 1 year (2014–2015)	Cohort	Multiple	Qualitative Longitudinal How to support sustained engagement in engineering design? What forms of engagement matter/for who/why? what are the equity implications when designing makerspaces for minoritised communities

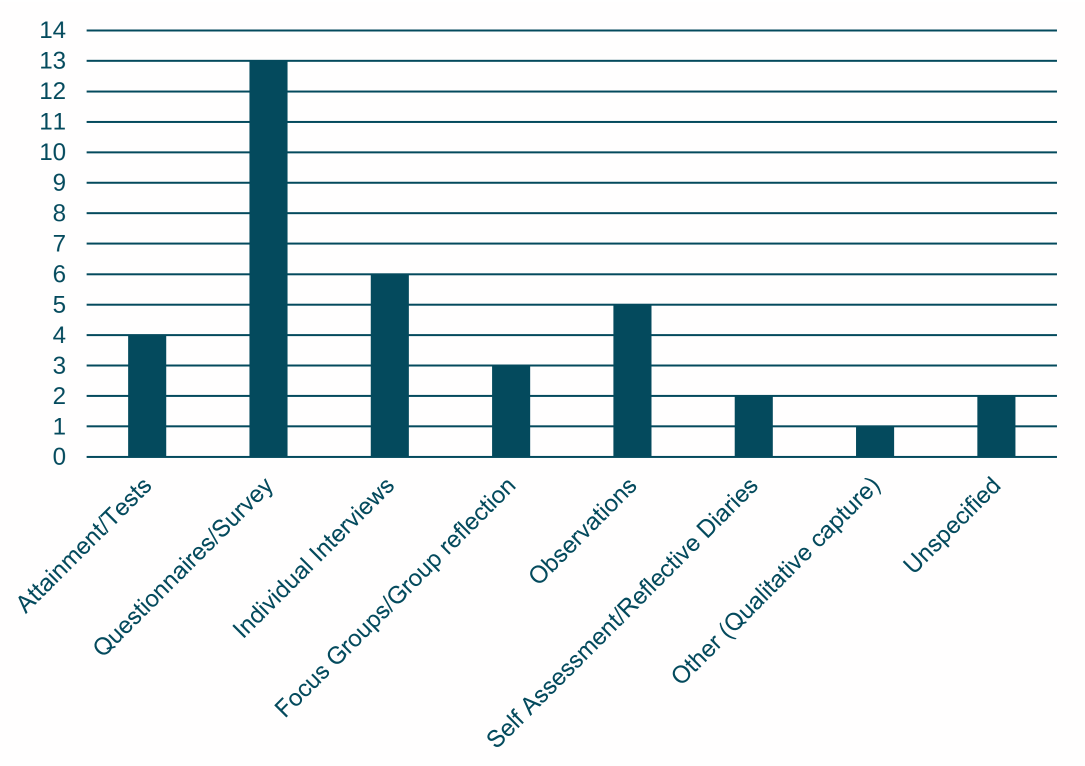
Study N°	Title	Year	Project Report or Published Pater	Primary Audience For the intervention	Numbers of participants in overall study	Cohort, case control RCT or Case study	Single or Multiple interventions	Measures
11	Ideal pictures and actual perspectives of junior secondary school science: comparisons drawn from Australian students in an astronomy education programme	2017	Published Paper	School-aged children (aged 11-15)	30 schools, 1427 students (Regional programme)	Cohort	Single (1 day training + ongoing online/phone support)	Cross Sectional questionnaires for students (Baseline and outcome) and sample interviews measuring Student perceptions of science in school
12	"I'm An Astronaut Get Me Out Of Here"	2017	Final Project Report	School-aged students (aged 9-18)	2004 log-ins (National programme)	Cohort	Single (Multiple?)	Cross Sectional questionnaires for students (baseline and outcome) relating to attitudes about science and science careers (Mixed Methods)
13	Tim Peake Primary Science	2017	Independent Project Evaluation Report	Teachers and school-students (aged 5-11)	1400 primary schools (National programme)	Cohort	Single	Cross Sectional Student attainment (teacher report, surveys, interviews), enjoyment and engagement in science. Teacher confidence, using space as a cross-curricular context.Short-term and long-term impact of the project
14	Destination Space	2017	Independent Project Evaluation Report	School-aged children and Families	733,017 (National programme)	Cohort	Single	Cross Sectional (Mixed Methods) Evaluation of the programme's impact and success. Forms and interviews. Schools, teachers and families (941 evaluation forms returned)
15	Improving Gender Balance Reflections on the impact of interventions in schools	2017	Project Report	Teachers & school-aged students (11-18)	20 schools	Cohort	Multiple	Cross Sectional (Mixed Methods) Uptake of AS-level physics. Impact of gender-balance interventions on experience of girls in physics classroom, science identity and confidence

Study N°	Title	Year	Project Report or Published Pater	Primary Audience For the intervention	Numbers of participants in overall study	Cohort, case control RCT or Case study	Single or Multiple interventions	Measures
16	When Teachers Get It Right: Voices of Black Girls' Informal STEM Learning Experiences	2017	Published Paper	Female school-aged students (aged 9-13)	6	Cohort	Multiple (25 day summer camp)	Qualitative Cross Sectional Measures of what the participants valued in 'IAMSTEM'
17	Explore Your Universe Phase 3	2018	Independent Project Evaluation Report	School-aged children and Families	39,273 (National programme)	Cohort	Single	Cross Sectional (Mixed Methods) Evaluation the programme's impact and success. (Forms from 213 teachers and 4,282 students)
18	IRIS (Institute for Research in Schools)	2018	Project Impact Report	Teachers and School-aged children	8 projects. 4000+ students, 1000+ teachers, at over 170 different Activities (*5% of UK state secondary schools)* (National programme)	Cohort	Multiple	Longitudinal, Mixed Methods, (unclear evaluation methods) Measures student attainment, student destinations, Experience of STEM teachers, the efficiency of the hub model
19	Curiosity Round 1	2019	Independent Project Evaluation Report	Children and young people (81% were aged 5-15)	32 separate projects reaching 2,273 (National programme)	Cohort	Multiple	Cross Sectional (Mixed Methods) How informal science can support young people, and what difference that made, including: Self-belief, essential skills, positive relationships, positively empowered, emotionally well, physically safe

Nineteen studies were selected for final review (see Table 1). Fifteen studies utilised both quantitative and qualitative data to some degree. Three studies (7,10,16) focussed on qualitative methodology with only one study (6) using purely quantitative measurements for analysis. A variety of measurement tools were used, with questionnaires or surveys being utilised most frequently for data collection.

Figure 2

The Frequency of different Evaluation Tools used across 19 included studies



5. DISCUSSION

This discussion focusses on the results and recommendations within the final selected, relevant, quality-screened studies. It draws upon the understanding of intervention impacts reported within these papers to explore recommendations for the approach of content, methodology and evaluation for *Our Space Our Future.*

References to the included studies are provided throughout the discussion, for example (1, 2, 3) and refer to the Study Number in Table 1.

Themes of Good Practice across Interventions

Science as practical, fun and bringing something new

Studies included within this literature review that used the context of working within schools, support the view that interventions should demonstrate clear links to science curricula, be that subject area, how science works, scientific debate, ethics or scientific processes.

Strong themes also emerged from the literature about the importance of keeping science practical, hands-on and fun (19). For example, students highly valued interactivity within a national, informal physics and engineering engagement programme (17), specifically reporting on the enjoyment of the hands-on components and using novel equipment. Ninety-three per cent of 11-14 year old students thought that hands-on activities in a national space engagement programme in UK science centres would help them with school science (14). Carefully considered, high quality, practical resources, tailored to the school curriculum were also identified by teachers as the most important aspect of a national space project across 1400 primary schools (13). In a single-school study, using curriculum-focussed space resources (4), students noted their enjoyment of ‘science experiments in school’ but less enjoyment of ‘science lessons at school’, again indicating the enjoyment of practical, hands-on elements in science.

Within community settings, practical and novel experiences that bring new interactive ways to explore science, have also proven to be effective. During a Saturday science club (2), activities (such as building a prosthetic hand by improvising with washing-up gloves, pipe-cleaners and small toy-car motors) were invaluable in encouraging ‘experiential learning’ in STEM, translating complex ideas and subjects into something relatable, interactive and easier to comprehend.

As schools often lack specialised science equipment and resources, specialised teaching support, time to plan, and time to implement practical science (8, 17), *Our Space Our Future* should be supporting schools with novel, challenging, stimulating and hands-on science experimentation that can facilitate these positive learning experiences. It is also important to cater for a range of different learning formats, such as using drama and debate, creative and interactive activities and real scientists in school. This variety has proved to be an effective method for positive and sustained engagement with young people (5, 19).

Higher order thinking skills

Higher-order thinking is promoted by teaching that shifts the focus away from learning lists of facts and towards a focus on skills such as analysis, discussion, evaluation and inquiry. Scientific content lends itself to these valuable skills: critical thinking, problem-solving, as well as coping with challenge and failure (19), which has a positive impact on young people's experience of science and provides skills for wider learning.

A qualitative study investigating the experiences of girls at an informal summer science camp (16) also found that teachers who promoted the girls to think critically and creatively promoted their academic success and engagement in STEM learning.

A primary school teacher-training study called 'Thinking, Doing, Talking Science' (8) focussed a five-day training session on enabling teachers to make science lessons in primary schools more practical, creative and challenging; providing teachers with a range of strategies that aim to encourage students to use higher-order thinking skills. The approach had a positive impact on students' attitudes to science as well as a positive impact on attainment in science. Overall, 9-10 year old children in schools using the approach, made approximately three additional months' progress on those in the control group. There was evidence that this improvement was particularly marked for girls, children from socio-economically disadvantaged backgrounds, and children with low prior attainment.

Real science in school

The study 'The Blue Marble' (4) brought primary school students together with space scientists, satellite technology, environmental science and activities that included real-time, hands-on GPS mapping. They emphasised that 'anyone can become involved in science, whatever their ability or subject of interest'. They extended this to challenge stereotypes of science being hard and 'not for me' by suggesting that the children were already space scientists, having run activities that use observations, modelling and even real satellites during the day. The feedback from this session was very positive. The statement of 'I should like to be a scientist' increased from 20% to 44% and a 19% agreement with the statement 'science is too difficult' reduced to 7% after the activity.

Another study that had an impressive impact on progression at A-level and the numbers of students continuing to study STEM after school is IRIS (Institute for Research In Schools) (18). They also bring real-world, cutting-edge scientific experimentation and research into schools. Alongside considerable support and guidance for teachers, they open up active scientific projects to students and their teachers and give a true taste of modern science. Some students have even written scientific papers about their work while still at school[13]. Student reports from their involvement with the IRIS project are reflective of how it made them feel like a pioneer and expert in their school. Others also reflected how their involvement gave them an insight into what it might mean to be a scientist.

Keep it career-focused

A key goal of *Our Space Our Future* is to support and enable students to feel that space science is 'for them' in terms of future subject and career choices. Space or STEM-related industry connections and future careers were explored to some extent in 15 out of the 19 included studies, making this one of the strongest themes across the review. The areas explored were in five broad categories:

- Attitude change towards consideration of STEM subject or occupational choices following an intervention (2, 4, 9, 12, 14, 17, 18)
- Increased knowledge/awareness of the wide diversity of careers related to or supported by STEM (2, 4, 5, 7, 9, 12, 13, 14, 18)
- Challenging stereotypes of science and scientists (4, 9, 10, 12, 14, 15, 18, 19)
- Helping students to see the relevance of science in their daily lives (5, 7, 9)
- The value and transferability of STEM skills and qualifications for wider careers (7, 12)

Valuing interests of the participants

Many studies incorporated and emphasised a change towards a more participatory practice model for engagement, enabling the children and young people to bring their own interests to the programme. The ability to work with students' interests, strengths and needs, supports this active participation. In Italy, UNAWE (3) asked

[13] Furnell et al. (2019) 'First results from the LUCID-Timepix spacecraft payload onboard the TechDemoSat-1 satellite in Low Earth Orbit'. https://bit.ly/2XJ2KEl

the children for their areas of interest, subsequently focussing their interventions on the suggestions that came from the students. Their procedure promotes the 'Reggio Approach':

"Rather than seeing children as empty vessels that require filling with facts, Reggio educators see children as full of potential, competent and capable of building their own theories." [14]

In Australia (11), alongside resources to promote practical, inquiry-based and investigative ways to teach astronomy, students were given the opportunity to select the objects they were most interested in for telescope investigation. This study found highly significant positive changes in the perception of and interest in science after involvement in the programme. However, it should be noted that in a similar study (6), despite the same capacity to choose their own topics to investigate, students did not perceive the material (using research telescopes for astronomical viewing) to be relevant for their future or useful to their everyday lives and there was little change to the students' excitement, curiosity, levels of challenge or enjoyment in school science. This study (6) also found a correlation between the teacher's familiarity with material and students' attitudes. Differences in the methodologies of the two studies may, therefore, underpin the different outcomes of the same intervention, as levels of ongoing teacher support, supporting resources and attempts to make connections with student experiences and surroundings varied between the two studies.

Making it relevant

Relevance is a key, recurring theme throughout studies included in this review. Making physics relevant was a key goal of the 'Improving Gender Balance' work by the Institute of Physics (15). 'Curiosity' is a programme investigating the value of bringing more informal science learning into voluntary and community sector organisations who work with children and young people experiencing disadvantage. The hands-on nature of the science, coupled with the high degree of activities being directed by the children and young people, was considered to be crucial to their continued engagement and to support the idea of science being something relevant and 'for them' rather than a remote concept (19).

'I AM STEM' is a summer camp programme built on the premise that the everyday home and community environments of the students profoundly influence their experience of science. They embraced a culturally relevant curriculum to pique

14 Reggio Emilia Philosophy. https://bit.ly/2vsK9jL

interest and curiosity, and ensured that the participating girls understood the relevance and applicability of the content to their everyday lives (16).

The hands-on environment of a 'Makerspace' (10) and the activities within this programme were creative, playful and entirely student-led, leading to meaningful processes, framed by the participants' lived experiences, such as solutions they developed to respond to sexual violence, bullying or socio-economic injustice. The science and engineering content was brought to the tasks at hand, complementing and deepening the making experience and allowing for 'just-in-time learning' – providing students with access to the right amount of information at the right time to progress with their own goal, therefore showcasing the relevance of STEM in bite-sized, goal-orientated chunks.

Put the participants in the driver's seat

Traditional school science shows encourage performance and showmanship and often put the science communicator on a pedestal for their science knowledge and presentation. Innovations are now taking place to disrupt this power dynamic or challenge the traditional teacher-learner relationship and teacher-centred classroom, which appears to be a valuable strategy for including individuals who are currently less engaged in science.

'I'm an Astronaut: Get Me Out of Here' (12) allows for the students to be the judges, putting the professionals on the spot to answer their questions and students then vote for their favourite space scientist at the end.

Within one strand of the 'Improving Gender Balance' work (15), students had 'science ambassador' training, allowing the girls involved in the study to become science outreach ambassadors themselves, developing and running workshops with primary schools. The study noted that this not only built confidence but also science identity, supporting science capital for these girls.

Another opportunity for students to showcase and celebrate their work is to enable them to become the ambassadors of science at conferences (18) or whole-school or community events. This again allows for the science engagement to be placed in the control of the students themselves, encouraging ownership of the science and development of new presentation skills. Celebration events are excellent events to encourage wider school participation (13) or bring in families to attend (3).

Inclusive science communication

Allowing time for group work and discussion were important aspects to emphasise the informal, fun, playful, pathway to learning, and to allow students to form interests collectively and pull on the experiences of others (2, 10). This may be particularly important for minoritised groups who need space to be created for their voices to be heard. For example, girls from a minority ethnic background, who are interested in science may be denied access due to a tendency to conform to silence in order to cope with academic situations where they are not included (10).

Methods that include students in debate, discussion and dialogue, bringing the students' voice into the engagement had very positive responses from teachers and students (5). A key recommendation from this study called 'Smarter' was to engage a broader range of the students in group discussions using established inclusive techniques ('take up time' or 'think-pair-share'). This was also echoed in recommendations from the Institute of Physics (15) who have a wealth of evidence and experience in tackling gender bias in physics in schools. 'Improving Gender Balance' worked with teachers and schools to improve the experience of girls in the physics classroom. The core recommendations of this work included tackling biases and stereotyping, particularly the importance of raising awareness and training in unconscious bias. Inclusive teaching techniques were encouraged such as using 'Plickers' to reduce the need to raise hands or shout out answers, having an impact on the experiences of girls and boys. Inclusive practices also included aspects such as maintaining awareness for gender-biased examples and gender stereotypes in the school environment, ensuring that roles during practical activities were rotated, challenging sexist comments and bullying, and integrating physics-related careers, exploring the social relevance of physics. They also raise the point that your bias is easier for someone else to spot, so having a third-party observing your lessons can be a powerful eye-opener.

The importance of gender balance was brought into the design and delivery of national space and physics programmes by the Association for Science and Discovery Centres (ASDC) (14, 17) where the outcomes had very little difference between boys and girls, both being equally positive about the activities and experiences and future interests following involvement in the programmes.

The Tim Peake Primary project in schools (13) also found that the subject matter and their approach encouraged engagement from young people, such as girls, who would otherwise not usually engage. The Discover! Programme (2) was a same-sex programme for girls, and although the overall benefits of this were inconclusive, the challenge to a cultural stereotype of 'science = male' is powerful to promote ownership, entitlement, affirmation and confidence for the students attending.

Nurturing a 'Growth Mindset'

The importance of ownership may extend beyond science and be a strong influencing factor in attainment when ownership is taken over personal learning. "Growth mindset" is the name given by psychologist Carol Dweck[15] to the idea that intelligence can develop, and that effort can lead to success. The belief that you can improve (rather than a belief that intelligence and talent are pre-determined and fixed) supports improvement.

This was explored in two articles (1, 15) where the message of a malleable intelligence, or an open or closed mindset, were part of the interventions. Stereotypes encourage a closed or fixed mindset and were a core part of the interventions in the 'Improving Gender Balance' programme (15). In their randomised controlled trial, Blackwell et al. (1) found that students' 'theory of intelligence' (whether they considered intelligence to be malleable or fixed) was key, and a message that learning changes the brain, and that the students are in charge of their intelligence, resulted in significant positive changes in motivation and achievement in mathematics.

Excellent facilitation of interventions

A final resounding theme across studies was the responsibility for excellence that rests with the facilitator or education professional. Many of the following themes have already been discussed as key aims of the included studies. However, the following attributes have also been explicitly addressed as guidance for good practice for facilitators and educators. Some of these skills are closely aligned to those of qualified youth workers and they are highly influenced by the in-depth qualitative analysis of the more community-based interventions explored within this review.

Facilitators of interventions should:

- Respond to the needs of the participants (16)
- Allow a youth-led approach (16, 19)
- Make the science relevant (16, 19)
- Encourage participants to think critically (16)
- Build a relationship, trust, mutual respect and be patient (11, 16)

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[15] Carol Dweck: A Summary of The Two Mindsets And The Power of Believing That You Can Improve. https://bit.ly/2ok2jk8

- Be culturally aware (10)
- Be curious themselves and willing to learn (10, 16, 18, 19)
- Bring creativity into science (10, 16)
- Be flexible, responding to questions, opportunities for wider interest and students' needs in the moment (10, 16, 19)
- Challenge students to reach their full potential (16)
- Have strong content knowledge (10, 16)
- Build a community of learners (16)
- Interact and include families in professional, open and engaging ways (16)
- Be able to articulate the breadth and diversity of STEM / STEM careers (2, 19)
- Facilitate interactions with real science and scientists (5, 10)
- Create a supportive, welcoming and safe space (2, 16, 19)

Support for *'Our Space Our Future'* Methodology

Multiple interventions

Our Space Our Future methodology is supported through this review. Eleven of the 19 studies had multiple engagements built into the design of the methodology and the single-visit studies also yielded recommendations of sustained and multiple implementations (5,6).

Outreach: going to where they are

The importance of going to where the students are, not only in terms of interest and values but also physically, was supported by the studies within this review (10, 19). Context matters, and opportunities of wider venues other than schools, such as community or youth-centred spaces, should be considered if the interaction takes place outside of the partnering school. These spaces are accessible, safe, supportive, familiar and enable wider interactions with peers and familiar community members (2, 10, 16, 19). Non-school settings to explore science for teachers (such as science centres) were also encouraged as venues that are rich with opportunity for educationally-framed, real-world phenomena (7).

Online engagements, providing two-way communication with students through websites and social media can also be a powerful strategy for a wider geographic and demographic reach. The Principia Project 'I'm an Astronaut: Get Me Out of Here' (12) allowed students to ask questions and hold live text-based chats with a team of space scientists. Participation was high (85%) and the programme improved students' attitudes towards science, particularly those who were less interested in science jobs before participation.

The importance of teachers

Teachers are integral to the success of any intervention in school, particularly in terms of the legacy of approaches such as 'Improving Gender Balance' (15), supporting science capital (7), supporting cross-curriculum teaching of space, the teaching of science and careers (8, 13) or the implementation and prolonged engagement with practical resources that promote higher-order thinking and real-science approaches (1, 3, 6, 8, 11, 12, 14, 17, 18).

The importance of the teacher's role and how school science is implemented is clearly a crucial contributor to students' attitudes and perceptions of science (11), as perhaps seen between two very similar studies with different outcomes (6, 11), where one main variance that was noted between the two study methodologies was the level of teacher support provided for sustained professional development.

When considering teacher Continuing Professional Development (CPD), the benefits to the teachers should be a core consideration of *Our Space Our Future*. UNAWE in Italy considered teacher curiosity as well as changes in practice as key indicators of the success of the programme (3).

For some interventions, the teachers took a more supervisory role and it was noted that for legacy, a project should facilitate lasting active links between teachers and networks of space scientists, engineers and university departments (5).

Improved subject knowledge, confidence and self-efficacy following pairing trainee teachers with student engineers in a mentoring partnership (9) had very positive implications for teacher performance and their own future careers. The process for the teachers of actively learning from an industry representative (and vice versa) was also highly valued.

The Institute for Research in Schools has demonstrated that developing complex professional networks has a positive impact on teachers' sense of professional worth and self-belief (18). Through participation in IRIS projects, teachers can transition from 'teacher' to a 'teacher-scientist' professional identity.

"For teachers who love science, it can be demoralising to have to do the same old experiments over and over again – we crave something original. To truly enthuse about our subject, our own interest needs to be piqued and our skills challenged."

Director of the Institute for Research In Schools (IRIS)

Professional networks were also encouraged in the Tim Peake Primary Project (13) through CPD events provided for one or two members of staff from multiple schools. This supported active local networks that have increased, providing opportunities for sharing resources, sharing good practice across project schools and extending the reach of the programme. This 'hub' model of schools is currently being evaluated by the Institute for Research in Schools to ascertain whether it provides an effective support system to increase positive impacts on student/teacher participation, whether it is supportive of continuation into STEM subjects and careers, and impacts on teacher retention.

The Tim Peake Primary Project (13) also saw a positive impact on the confidence of teachers teaching space science, their role being supported by expert 'Space Ambassadors' who worked alongside the teachers to develop a bespoke action plan for individual schools. In addition, when the CPD was provided to at least half of the teachers, it was more likely to result in activities that involved the whole school, extending the longer-term impacts for teachers and student outcomes.

UNAWE also noted that the most effective courses were those where the activities were carried out, not only to train the teachers alone, but when the teachers and the children were engaged together at the schools (3). Both these examples, support the 'whole school' approach – a productive method for many of the included studies and a key recommendation from the Institute of Physics. Their intervention also worked better when there were multiple staff members across the school and at different levels (leadership being important). The Drayson Pilot project (15) increased the number of girls taking AS-level physics from 16 to 52 (more than trebling over two years). Their methodology relied on the whole school being involved, not just science or physics (for example, they ran whole-school INSET days on unconscious bias and mindsets, and whole school audits were performed to identify gender stereotyping). Advocacy at the leadership level was also highlighted in other projects, with headteachers being an important first step to engaging with the schools (13)

"Increasing girls' participation in physics should, at least in part, operate across the whole school, involving students, teachers of physics and of other subjects, senior leaders, parents and governors." (15)

Engagement with parents

There was little formal evaluation of the specific impact on parents despite several studies supporting active involvement from parents and wider families (3, 14, 17, 16).

The 'Discover!' Saturday club programme considered that parents, even if they are not actively involved in the sessions, are gatekeepers to participants' STEM experiences - listening to reflections, extending and sharing ideas and becoming champions to sustain the interests of participants. (2)

One of the three attributes that girls said encouraged their learning and promoted academic success during a community-based summer programme, was teachers who interacted with their parents positively and professionally (16).

The need to engage with parents in terms of career guidance was also highlighted in a survey in one school of 100 students (aged 13-14), where 87% of students had discussed future subject choice options with adults at home, but only 34% had discussed these options with teachers (15).

Independent evaluation of the Tim Peake Primary Project recommended a greater focus on engaging with parents to support the children's learning and improve outcomes, either through encouraging direct engagements with parents coming into school or developing 'take-home' resources for students and their families to engage with outside of school.

"Expert voices are crucial, but they are not the only advice that matters" (10). Considering the immense influence that families have on student's aspirations[16], and enabling engagements with families should be a core commitment of *Our Space our Future*.

Evaluation of impact

Currently, student outcomes are measured through attainment as well as a large majority of studies investigating attitudes and perceptions of science, science in school and science as a future career.

Encouraging the feeling of belonging and confidence with science has also been captured: 'I felt welcome', 'I was able to join in and be part of the activities" (17), and some studies support the widening perception of science providing transferable

[16] Archer, L. et al. (2013) 'Aspires: Young people's science and career aspirations, age 10-14'.https://bit.ly/2DPCnFl

skills: 'when you finish your education, how likely are you to look for a job that uses your science knowledge and skills?" (12).

In planning the evaluation strategy for *Our Space Our Future*, recommendations for capturing meaningful data also include:

- Measuring the impact on teachers, benefits for their practice and their curiosity, while maintaining an understanding of what they deem to be feasible to implement considering their capacity and time constraints.
- Ensuring that parents and wider families play a meaningful part in the evaluation.
- Use of qualitative data to capture detail, value individuals and explore the specific experiences of students that lead to attitudinal change.
- Maintaining awareness for the unexpected, unplanned but meaningful outcomes.
- Ensuring outcomes of training and reflection are captured for delivery partner practitioners, considering the importance of excellent facilitation.

Finally, from the learning of a number of studies that were excluded from this review due to weak methodology, *Our Space Our Future* intends to have a robust, longitudinal evaluation that offers recommendations to external practitioners to help address this gap and contributes to the pool of European science-education research.

6. CONCLUSIONS

Although we acknowledge there is no 'one size fits all' and no 'magic bullet' that works to engage, inspire and involve all school-aged children, this review of the available primary research brings together the following seven themes as the most relevant and prevalent recommendations to take forward for the development, delivery and evaluation of *Our Space Our Future*. Suggested links to specific studies for capacity building and research from within and beyond the consortium network are also noted.

1. Get hands on with real science skills

STEM engagement for greater impact is becoming less about facts and more about developing a positive science identity, particularly when engaging marginalised groups in science. *Our Space Our Future* should not shy away from challenging students and should promote higher-order, critical thinking that enhances classroom science for students and teachers. Enabling and facilitating real, modern science in school, and promoting students and teachers into science, is an exciting direction for *Our Space Our Future.* However, the key recommendation is to keep the series of interventions practical, hands-on, varied and fun, to nurture curiosity and stimulate new ways of thinking about science.

Considering the value of STEM engagement, programme facilitators should also remain mindful that our delivery should be something of universal value, not solely directed for those who may take up space-related careers in the future[17], but taking a wider view of space sciences as enhancing, exciting, valuable and, above all, relevant for all.

Recommendations for capacity building:

- The universally positive and relevant outcomes from 'Thinking, Doing, Talking Science' (8), is a key programme to link with for teacher CPD.
- The 'Blue Marble project' (4), bringing Earth observation satellite technology directly into schools, had exceptionally positive results and is of great relevance for the content of *Our Space Our Future*.
- *Our Space Our Future* could learn from creative-based activities and methods for prolonged and repeated engagements such as those from the 'Discover!' Project (2) and Makerspaces (10).
- Promoting student-centred approaches and encouraging interdisciplinary and inquiry-based learning are key themes within toolkits developed for

[17] Osborne, J. & Dillon, J. (2008) 'Science Education in Europe: Critical Reflections'. https://bit.ly/2RfBCdr

teachers using the PLATON methodology, a relevant programme for the development of teacher training within *Our Space Our Future*[18].

- Additional research can be found that supports the need to encourage students' natural curiosity, apply scientific ideas to practical, inquiry-based activities and ensure science is fun, leading to positive student outcomes in attitude and achievement[19, 20, 21].

2. We should not 'design for' or 'do to', we should 'work with'

To disrupt a more traditional power dynamic of 'science expert' and 'pupil', *Our Space Our Future* should allow for the participants (students, teachers, families) to influence the development and delivery of the programme. Regardless of disadvantage, science is relevant to young people's lives (19). Highlighting the relevance of science to everyday life can be challenging, depending on the facilitators' local community or cultural understanding, but a more flexible, participatory approach to the *Our Space Our Future* toolkit will allow for greater contextuality and relevance, as participants' own interests and experiences lead the direction of sessions. Although difficulty striking the right balance between 'expert suggestion' and youth 'going their own way' (10) should be expected, giving the ownership of the science to young people will support continued engagement over multiple interventions and nurture a growing identity with space science from a greater breadth of learners.

Recommendations for capacity building:

- Connections with individuals from community organisations involved in the Curiosity Round 1 study (19) may provide useful insights, alongside maintaining awareness as the learning from Round 2 is disseminated.
- The current Science Learning + programmes are funded jointly by the Wellcome Trust/ESRC and the National Science Foundation, working across the UK and USA. The goals are to gain a greater understanding of the power of informal learning experiences, both inside and outside school environments. Although several programmes do not complete until 2021,

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[18] Platon Roadmap Towards Innovation: Promoting innovative Learning approaches for the teaching of Natural Sciences (2018) https://bit.ly/2DCG94E

[19] Science and the Youth Sector: Context matters for disadvantaged young people and informal science activities (2017) https://bit.ly/2f4WyCa

[20] Osborne, J. & Collins, S. (2011) 'Pupils' Views of the Role and Value of the Science Curriculum: A Focus-Group Study'. https://bit.ly/2UPOVlA

[21] Maintaining curiosity: A survey into science education in schools (2013) https://bit.ly/2V5vpGw

many will continue to provide valuable learning that can be brought into *Our Space Our Future* during delivery[22, 23, 24].

- The art of remaining relevant is becoming a core practice. The need to 'humanise' science and show its relevance in our history, culture and present-day was a recommendation from the ROSE Project[25]. This project also highlighted the importance of bringing the values, interests and attitudes of the students into a higher priority if we are to engage in meaningful learning. The importance of students directing their own learning, and educators building on what students bring to the lessons, are also the first 2 guidance points in a recent report for science teachers from the Education Endowment Foundation[26].

3. Celebrate success and bring in the wider family and community

Celebrating learning and successes with families and wider communities have a powerful impact. Students become the science communicators, placed in positions of trust and responsibility within the partnership, with the opportunity to be creative, communicate their passions and become the 'agents of change' for audiences.

Recommendations for capacity building:

- UNAWE in Italy involved children designing their own planetarium projections and narrating shows for their families at a final celebratory event (3).

Learning from the EU H2020 PERFORM programme provides a toolkit of tested methods to generate transformative participatory educational processes by using arts-based approaches, alongside communication and performance skills for students. It also contains excellent examples of how students shared their work with their wider community[27].

4. Keep it careers-focused

Our Space Our Future highlights both the breadth of careers from science and the relevance of science to many areas of everyday life. To fully integrate space science

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[22] Science Learning +: Partnering for Equitable STEM Pathways for Underrepresented Youth. https://bit.ly/2IF9O11
[23] STEM Teens: Examining the role of youth educators as learners and teachers in informal STEM learning sites https://bit.ly/2DucwT9
[24] The Role of Identity in STEM Learning and Science Communication: Reflections on Interviews from the Field. https://bit.ly/2GoJlkM
[25] Sjøberg, S & Schreiner, C. (2010) 'The ROSE Project: An Overview and Key Findings'. https://bit.ly/2zsYNMR
[26] Education Endowment Foundation (2019) 'Improving Secondary Science: Guidance Report'. https://bit.ly/2UNI38f
[27] PERFORM: Participatory Engagement with Scientific and Technological Research through Performance. http://www.perform-research.eu/toolkits/

careers into the classroom requires time, knowledge and capacity which many teachers do not have, alongside logistical barriers such as limited availability of work placements or a lack of strong contacts with STEM industry ambassadors (15). The symbolic knowledge about the transferability of science is also an important dimension of science capital that teachers may feel is outside their remit and beyond their responsibility (7). Challenging perceptions and stereotypes by having female scientists and scientists of diverse race and backgrounds involved in workshops, or as leaders, nurtures the sense that a scientist can be 'someone like me' (4, 10).

Raising the profile and awareness for the diverse breadth of space and space-related careers, alongside seeking suitable experts, given the underrepresentation of particular populations in the STEM industries, is a challenge (10), but it is one more easily addressed by the delivery partners and an area of support that *Our Space Our Future* can offer the schools we work with. Wider research has demonstrated that students possess more positive attitudes to science when learning is led by application rather than theory[28]. Given that a fundamental characteristic of the Our Space Our Future initiative is to deliver STEM subjects through a medium of space science and space-related careers, this application focus will be embedded within all activities of Our Space Our Future.

Recommendations for capacity building:

- A Meet the Expert format from 'Explore Your Universe Phase 3' (17) or 'SMARTER' (5) allows for face-to-face interactions with industry or research professionals with support from facilitators and practical equipment to bring their area of science to life. These sessions have mutual benefits for all stakeholders.
- 'I'm an Astronaut: Get Me Out of Here!' is an internationally-reaching, ongoing programme. Discussing their approach for schools of meaningful, online interactions with scientists, may provide opportunities for schools remote from centres of STEM industry and research to make these connections.

5. Challenge unconscious bias

One of the most effective ways to challenge stereotypes is to train teachers and raise awareness for students of stereotyping and unconscious bias, and the many ways in which it impacts our daily lives. For example, teacher and student audits of gender or race bias can take place in the school (displays, textbooks, examples

[28] Reid, N & Skryabina, E. (2002) 'Attitudes towards Physics'. https://bit.ly/2WfWvaD

given by teachers) or when considering external marketing in products, and previously unnoticed biases start to become policed by the whole school:

"Once someone understands their biases, they are often surprised that they have them, but can work to manage them." (15)

To support science identity and confidence, *Our Space Our Future* must ensure that we are using inclusive science facilitation techniques and designed-in opportunities ourselves, to support seldom-heard and minoritised voices.

Recommendations for capacity building:

- Connections with the work of the Institute of Physics Gender Balance and Gender Balance Scotland Programmes to incorporate their research, resources and wider networks to provide best practice for unconscious bias training and inclusive teaching methods across our programme(15).
- The EU H2020 Hypatia Project provides toolkits for communicating science in a more gender-inclusive way, including recommended formats for engagement, promotion of youth panels and young advocates for gender equity, and guidance for facilitators and STEM industry professionals that challenge unconscious bias[29].

6. Bring a whole-school approach to our engagement

Building relationships with schools is of the highest priority in order to create a lasting partnership that is of equal value to both sides and is sustained throughout the project delivery. For each school, delivery partners will need to take time to understand school priorities, needs, motivations, strategic plans, objectives, and how those can be realised through a partnership with the project. Alongside training events run by *Our Space Our Future* for teachers, the teachers' skills, experience and knowledge must be brought into delivery (5), and consortium partners should have a good understanding of how they can best support the school's agenda and 'fill the gaps'.

Networking with the school's local STEM organisations and community groups can promote knowledge of local, meaningful and authentic interactions. Working with headteachers (and ideally gaining trustee/governor support) is an ideal first step. Supporting inspection goals (e.g. Ofsted in the UK) is also valuable for the school

[29] HYPATIA Project, Expect Everything. http://www.expecteverything.eu/hypatia/toolkit/

(13). Engagement with the whole school, encouraging greater participation in teacher CPD and increasing the likelihood of whole-school or wider celebration events, increases the impact for schools involved.

Recommendations for capacity building:

- Tim Peake Primary Science Project (13) Space Ambassadors worked closely with schools to provide bespoke plans for each school delivery with great success and positive outcomes.

7. Build in legacy

Teachers benefit from partnerships with industry personnel (9) and being networked with professionals in industry or other participating schools (18). There are benefits to teachers in terms of careers knowledge, confidence, self-efficacy, self-belief and professional worth and identity. In addition, stronger connections to industry, research and wider professional networks open up opportunities for longer-term, more in-depth engagements for students such as work placements[30].

Therefore, *Our Space Our Future* should encourage all opportunities that allow for stronger links between teachers/schools and local space scientists, engineers, industry networks or university departments. Mechanisms should also be put into place to support flourishing networks of teachers[31], working within local schools, or between the cohort of project delivery schools (13, 18). Supporting professional networking for teachers and schools is an opportunity to catalyse embedded changes in practice and provide a valuable legacy as part of the *Our Space Our Future* project design.

[30] Ten Science Facts & Fictions: The Case for Early Education about STEM Careers. https://bit.ly/2UQPMqZ
[31] Doran, R. (2014) Building Bridges and Creating Communities with Innovative Technologies https://bit.ly/2GSIDOr

7. LIMITATIONS

Online electronic searches were utilised to minimise the consortium-focused research bias. However, despite all project partners inputting papers from across Europe, relatively few primary research studies, investigating interventions emerged from the literature provided. There appears to be a limited number of primary research papers investigating the impact of an intervention. The inclusion of project reports allowed for a larger range of studies to contribute to the synthesis, as the selection would otherwise bias university and academic-linked establishments only. However, this meant that many of the studies were plagued with insufficient information or weak methodology. A critical analysis that addressed areas of study design and evaluation therefore favoured peer-reviewed published papers over informal project reports due to the need for robust and replicable methodology alongside confidence in results. Aspects of experimental design considered core requirements in scientific papers (such as sampling and selection bias, control groups, acknowledgement of variables, stated ethical considerations or the benefits of baseline or follow up data) were lacking in many studies. Gender, ethnicity and socio-economic disadvantage were also considerations promoting a more audience-focus to engagement, but they lacked consideration of intersectionality (where different aspects of diversity, for example; race, socio-economic disadvantage, age or gender, may overlap) when discussing diversity.

Research has shown that similar patterns in student attitudes and experiences are seen internationally[32], however, another limitation of this review is that 13 of the 19 included studies are from UK-based research, where we had hoped to represent a broader pan-European cross-section of the STEM and space intervention research taking place.

Finally, a wide variety of tools were used across the included studies. It was beyond the scope of this review to check whether the differing questionnaires had been validated in relevant populations. However, the same standardised tool to assess students' perceptions of science was only used in two studies (6, 11). Recognised, easily administered tools for use with school-aged students would be a useful step to enable more rigorous comparison across project outcomes.

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[32] Lyons, T. (2007) 'Different Countries, Same Science Classes: Students' experiences of school science in their own words'. https://bit.ly/2GHs4ng

8. ACKNOWLEDGEMENTS

We would like to offer a special acknowledgement to Jim Bell, Explorer Dome and Sophie Wang, UCL for their support, time and expertise during the article research for this review.

9. CONFLICTS OF INTEREST

Members of the consortium feature in selected studies (for example Explorer Dome and Science Made Simple were delivery partners in SMARTER). Shaaron Leverment is currently the Deputy CEO of the UK Association for Science and Discovery Centres, the science centre membership organisation who authored two of the included project reports. However, having not managed or directed either project or been involved in the authorship of the reports, Shaaron states no conflict of interest.

10. FUNDING

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821871.

11. APPENDIX I

Checklist for cohort or case control studies

Does the study address a clearly focused issue:

1. Is there a clearly defined (research) question addressed by the study?
2. Is the methodology clearly defined enough to be replicable?

Quality of data:

3. Does the study include evaluation of quantitative or qualitative data?
4. Is the quantity and quality of data/findings sufficient? For example, is there more than a single yes/no question within this study that relates to our research question?

Study design:

5. Were participants recruited in an acceptable way that avoids selection bias?
6. Does the study design include an appropriate control or reference group?
7. Was the study longitudinal, involving the collection of suitable baseline and/or follow up data?
8. Were all participants who started the trial properly accounted for at its conclusion?

Variables and Independent differences:

9. Did the study state clear exclusion criteria?
10. Did the study design attempt to control for or discuss other variables

Ethics

11. Is it possible to ascertain whether the study obtained both ethical approval prior to the start AND whether participants provided informed consent?

Outcomes:

12. Was gender, ethnicity, disability, socio-economic disadvantage (or other groups) a consideration in this study?
13. Is there discussion of intersectionality when discussing diversity?
14. Does the subject matter include consideration of career links or space industry-related science?
15. Are the results obtained reliable, do you have confidence in their conclusions?

12. APPENDIX II

Checklist for qualitative studies

Does the study address a clearly focused issue:

1. Is there a clearly defined (research) question addressed by the study?
2. Is the methodology clearly defined enough to be replicable?

Quality of data:

3. Does the study include evaluation of qualitative data?
4. Is the quantity and quality of data/findings sufficient?

Study design:

5. Were participants recruited in an acceptable way that avoids selection bias?
6. Is a qualitative methodology appropriate for this study?
7. Was there a suitable method/structure for collecting the data?
8. Was the setting and/or relationship with the researcher considered in the study?

Variables and Independent differences:

9. Did the study state clear exclusion criteria?
10. Did the study design attempt to control for or discuss other variables?

Ethics:

11. Is it possible to ascertain whether the study obtained both ethical approval prior to the start and whether participants provided informed consent?

Outcomes:

12. Was gender, ethnicity, disability, socio-economic disadvantage (or other groups) a consideration in this study?
13. Is there discussion of intersectionality when discussing diversity?
14. Does the subject matter include consideration of career links or space industry-related science?
15. Are the results obtained reliable, do you have confidence in their conclusions?

13. APPENDIX III

Checklist for RCT studies

Does the study address a clearly focused issue:

1. Is there a clearly defined (research) question addressed by the study?
2. Is the methodology clearly defined enough to be replicable?

Quality of data:

3. Does the study include evaluation of quantitative or qualitative data?
4. Is the quantity and quality of data/findings sufficient? For example, is there more than a single yes/no question within this study that relates to our research question?

Study design:

5. Were the participants and study personnel blinded?
6. Were the groups similar at the start of the trial?
7. Were the groups treated equally (except for intervention)?
8. Were all participants who started the trial properly accounted for at its conclusion?

Variables and Independent differences:

9. Did the study state clear exclusion criteria?
10. Did the study design attempt to control for or discuss other variables

Ethics

11. Is it possible to ascertain whether the study obtained both ethical approval prior to the start AND whether participants provided informed consent

Outcomes:

12. Was gender, ethnicity, disability, socio-economic disadvantage (or other groups) a consideration in this study?
13. Is there discussion of intersectionality when discussing diversity?
14. Does the subject matter include consideration of career links or space industry-related science?
15. Are the results obtained reliable, do you have confidence in their conclusions?

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