Baseline Evidence and Research Project for Gender Equality in STEM

Final report: 1. Literature review

Presented to **Welsh Government Office for Science** by **Arad Research**

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1. Introduction

The Welsh Government Office for Science commissioned Arad Research to undertake a Baseline Evidence and Research Project for Gender Equality in STEM. Three reports (and a separate infographic summary) were produced as part of the study's final outputs:

1. Literature review (this report).
2. Data review.
3. Stakeholders' views.

This report presents the findings of the literature review. It summarises the evidence, drawn from across the United Kingdom and internationally, of interventions which seek to improve gender equality in STEM (Science, Technology, Engineering and Mathematics) to enable an understanding of:

- what works;
- what lessons can be learnt;
- what interventions might be potentially implemented in Wales.

1.1 Definitions

It is important that the definitions of 'gender equality' and 'STEM' are clarified. In order to provide consistency with other Welsh Government outputs, the gender definition presented by Parken (2018) is considered – 'gender refers to one axis of social and economic stratification and not to biology. The social processes of gendering are carried through an oppositional binary, whereby differently valued roles, attributes, skills and behaviours are stereotypically ascribed to men and women' (Parken, 2018, p. 9).

With gender equality noted as being for 'for women and men, acknowledging that the social processes of gendering have negative impacts on women and men. Equality can mean variously equality of opportunity or outcome' (Parken, 2018, p. 9). However, it is apparent that this research places greater emphasis on investigating the opportunities and outcomes for females as their focus.

The Welsh Government emphasise the inclusion of Science, Technology, Engineering and Mathematics within the STEM umbrella (Welsh Government, 2012, p. 3; Welsh Government, 2016, p. 2) and the inclusion of Medicine too (Welsh Government, 2017a, p. 1). However, 'STEM' is potentially 'vast and complex' (US National science Foundation, 2010, p. 15), yet with a lack of a universally accepted definition in education and the employment sector (National Audit Office, 2018, p. 5). It has been proposed that there is no need to 'force a unique definition' (Siekmann, 2016, p. 2). To capture the research literature available, for the purposes of this review STEM is interpreted in its broadest sense, as can be seen from the search terms used (Section 2). The data review groups subjects accordingly and includes STEM academic subjects, STEM vocational subjects, Social Science subjects and other academic subjects.

1.2 Context

The Science, Technology, Engineering and Mathematics (STEM) professions are important to the vitality and success of a nation. However, there are skill shortages in the STEM sector and women are significantly under-represented. With women in the minority in STEM fields, UNESCO promote an overarching priority for gender equality at all levels of education and throughout women's careers (UNESCO, 2016, p. 3). In doing so UNESCO emphasise the importance of the sustainable development goal to 'achieve gender equality and empower all women and girls' (United Nations, 2019). If women's attainment in STEM increases it is reported that there would be a positive impact on the potential productive capacity of the economy (European Institute for Gender Equality, 2017, p. 53).

It is projected that by 2024 there will be significant growth in the proportion of professional STEM jobs in the UK economy (UK Commission for Employment and Skills, 2016, p. 73). Yet despite increasing numbers of women going to university and filling highly skilled jobs, there has not been a similar increase in the numbers of women employed in 'traditionally male-dominated scientific and professional fields' (European Commission, 2012, p. 44). The UK produces 36,000 fewer engineers than needed, and even though the proportion of females in the STEM workforce is rising, the UK has the lowest female participation rate in Europe (Macdonald, 2014, p. 11), and only 17 per cent of engineering and technology students at Welsh universities are female (HESA, 2019).

The Welsh Government's *Well-being of Future Generations (Wales) Act* highlights the importance for equality, with 'a more equal Wales' as one of the seven well-being goals (Welsh Government, 2015a, p. 6). A recent review of gender and equality policies in Wales reported that there is evidence of progress, yet achieving equality is dependent on 'creative and collaborative use of gender mainstreaming principles and tools' (Parken, 2018, p. 7); with 'a bold, shared vision for gender equality' needed (Davies, Furlong, and Wharf, 2018, p. 61).

In 2010 the Welsh Government launched the National Science Academy; 'a collaborative alliance of organisations with STEM interests (Welsh Government, 2012, p. 22). Since the launch of Science for Wales in 2012 (Welsh Government, 2017a, p. ii), the National Science Academy engaged young people in STEM by funding programmes, some of these are referred to in Section 1.3. The Welsh Government Office for Science now funds, promotes and co-ordinates STEM enrichment across Wales prioritising young peoples' engagement in STEM, including addressing the 'longstanding concern over loss' of STEM talent as girls and women choose not to pursue STEM study, leading to shortfalls in recruitment, retention and promotion in STEM research and employment (Welsh Government, 2017a, p. 5; Welsh Government, 2015b).

The Welsh Government emphasise the importance of an innovative, relevant curriculum for young people (Welsh Government, 2014, p. 18); and equity is central to the new curriculum developments in Wales (Welsh Government, 2017b, p. 17). Others support this noting that education is key to addressing gender equality and diversity issues in STEM (Holford and Lappin-Scott, 2016, p. 18); and although it has been recognised that there has been some progress in gender equity in STEM, 'interest and participation in STEM learning, particularly among girls' remain a priority in Wales (Welsh Government, 2016, p. 28).

1.3 Gender equality in STEM projects

This section provides a brief overview of a selection of STEM projects currently funded and delivered by a range of organisations. It includes a sample of activities which are available across the United Kingdom, examples unique to each of the four nations of the UK and more detail regarding a sample of activities available in Wales. Many of the activities are inclusive and open to all between specific age ranges. There are also some projects that specifically target female participation.

1.3.1 UK STEM-enrichment activities

Examples of pan-UK STEM-enrichment activities, include the CREST Awards[1], which recognise student-led STEM projects for young people aged 5-19. A range of activities have been delivered since 1986, which include one-hour long challenges to projects over 70 hours work or more. There are charges to participate in the CREST Awards, but for those participating in Wales the majority of the activities are listed as free, with the funding currently provided by the Welsh Government Office for Science. Participants based in other parts of the UK pay between £3-20 depending on the activity (CREST Awards, 2019). An evaluation of the delivery of CREST in Wales reported on the importance of the fee subsidy and concluded that if the subsidy were removed participation rates could half (Vector STEM Partnership, 2018, p. 2). Since 2010, participation in the CREST Award in Wales has risen from well below the UK average to twice the average (2016-17), and continues to rise. The Big Bang deliver a range of regional and national fairs to encourage hands-on STEM activities across the UK, including fairs in north and south Wales delivered in collaboration with Education Engineering Scheme Wales (EESW)/ STEM Cymru2. A high proportion of students participating in EESW/STEM Cymru also complete the Gold CREST Award, with figures significantly higher in Wales than in the English comparator region (2016-17 – Wales 527; North East of England 165 (Vector STEM Partnership, 2018, p. 1)). Table 1.1. provides more information on CREST and EESW/STEM Cymru.

A couple of examples of STEM enrichment programmes delivered in other UK nations include a Young STEM Leaders Programme piloted in Scotland and due to be fully launched in 2020,[3] which includes a youth steering group as a key element of this and a couple of case studies present findings from the pilot programme.[4] In Northern Ireland Deliberate Learning work in partnership with STEM Learning to deliver funded placements and courses for Science technicians and teachers.[5]

1.3.2 STEM-enrichment activities delivered in Wales

STEM Learning is a provider of STEM education and careers support across the UK[6] and Techniquest is the organisation's Science Learning Partner in Wales, with See Science[7] also working in partnership to deliver the STEM Ambassador Hub element. STEM Ambassadors are volunteers who connect with schools and colleges. Overall the initiative reports to benefit more than two million people across the UK, including teachers and

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[1] CREST Awards
[2] Education Engineering Scheme Wales
[3] Young STEM Leaders Programme
[4] Young STEM Leaders Programme Pilot case studies
[5] Deliberate Learning
[6] STEM Learning
[7] See Science

learners each year, including science teachers who report that they are more likely to remain in teaching following a STEM Learning professional development training (STEM Learning, 2019, p. 1). More information on the Welsh partners is included in Table 1.1. See Science[8] is an organisation providing science enrichment activities in Wales to all age groups and co-ordinates the STEM Ambassador Hub Wales.

Organisations such as the Institute of Physics, Institution of Civil Engineers and the Royal Academy of Engineering also support widening access and provide interactive activities for students, including projects delivered in Wales. Further information on some of these initiatives is provided in Table 1.1. The HEFCW (Higher Education Funding Council for Wales) funded First Campus initiative also includes STEM-engagement activities to encourage widening access to higher education for young people and adults, delivered by Cardiff and Cardiff Metropolitan Universities, University of South Wales and the Royal Welsh College of Music and Drama.[9]

Other initiatives which support widening participation in STEM study and careers across the UK for females in all age groups include the WISE Campaign,[10] working to increase the participation, contribution and success of women STEM. In September 2019, a Wales Women in STEM initiative was launched (also supported with HEFCW funding) to facilitate female participation in STEM at all career stages and is the host for the Welsh regional hub for WISE. Chwarae Teg also deliver a range of projects supporting young people and professionals across Wales e.g. Not just for boys – female students meet role models and learn about 'non-traditional' female careers and Agile Nation 2 – career development programme.[11]

Resources were not available to undertake a full audit of all STEM-enrichment activities delivered in Wales, yet the above examples provides some indication of the type of activities and organisations involved in supporting engagement and increasing participation in STEM. Table 1.1 provides an overview of a sample of some of the key organisations, current funding and the type of STEM-focused activities delivered across Wales, with Figure 1.1 presenting the location of some of these. Thus, illustrating the range of activities delivered across Wales. It is important to note that the projects are usually available to all, yet, in some instances an operational objective will be to increase female participation and some activities specifically target this.

The focus for this literature review is to learn what gender equality in STEM interventions work and what lessons can be learnt in order to identify the type of interventions that would potentially be implemented in Wales. Consequently, the emphasis for this review is evaluations of delivered interventions that seek to address the gender balance for studying STEM, and following STEM-related career pathways. The approach adopted for the review is discussed in the following section before a summary of the key findings are presented.

[8] See Science
[9] First Campus
[10] WISE Campaign
[11] Chwarae Teg – Not just for boys and Agile Nation 2.

Table 1.1. Examples of STEM projects in Wales

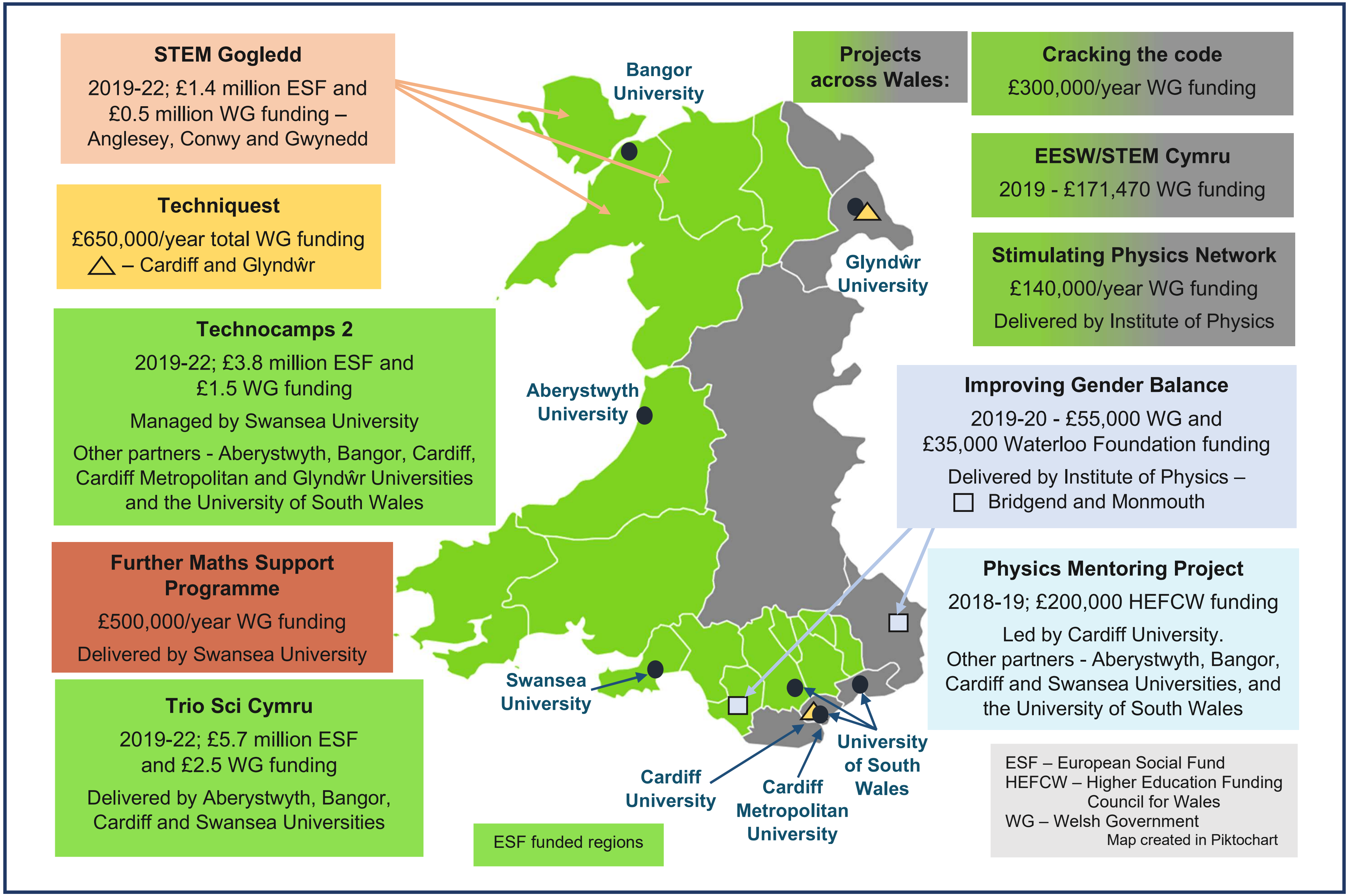
STEM project	Description
Cracking the Code[12]	Launched in 2017, £300,000/year over the Welsh Assembly's term - £1.3m (from the Education Improvement Grant). The funding is allocated to the regional education consortia for extra curriculum code clubs and also includes resources to code and learn to code in Welsh. Key stakeholders such as Code Club UK, Sony, the DVLA and Technocamps support Cracking the Code.
CREST	CREST is the British Science Association's flagship programme providing STEM enrichment activities for 5-19 year olds. The Welsh Government has subsidised the cost of CREST entries since 2010, with it currently channelled through the Welsh Government Office for Science. Participation in the Award in Wales has risen from well below the UK average in 2010 to twice the average, and continues to increase.[13]
Engineering Education Scheme Wales (EESW) /STEM Cymru	The organisation has delivered engineering activities to students across Wales since 1989, including some supported by the European Social Fund (ESF) until 2021. With the ending of the National Science Academy in Wales, Welsh Government allocated £171,470 of STEM Curriculum funding in 2019 to the organisation (more information on EESW activities is included in Section 3.2.1).
Further Maths Support Programme[14]	Delivered by Swansea University since 2014, funded by the Welsh Government £500,000/year. The programme is aimed at high achievers and with four strands of delivery; professional learning, free teaching resources, enrichment, tuition and student support.
Improving Gender Balance	£55,000 funded by Welsh Government and £35,000 from the Waterloo Foundation, the Institute of Physics is delivering this project (Sept 2019-Aug 2020), which aims to address negative gender stereotype when teaching STEM and involves two comprehensives and their feeder schools (Monmouth and Bridgend).
Physics Mentoring Project[15]	Led by Cardiff University, £200,000 - 2018 pilot year funded by HEFCW (Civic Fund). Delivered by Aberystwyth, Bangor, Cardiff and Swansea universities and the University of South Wales. 87 year 10/11 students and 21 university mentors (further information included in Section 3.2.6).
STEM Gogledd[16]	With £1.4 million ESF funding and £500,000 from the Welsh Government (2019-22), activities will include employer visits, employers and STEM ambassadors visiting schools, Saturday clubs for girls, for young people aged 11-19 years in Conwy, Anglesey and Gwynedd (2019-22). The project has a target of 600 pupils over the three years (60 per cent female).

[12] Cracking the Code
[13] A comparison of CREST in Wales and the North East of England reported 1,593 CREST Awards gained in Wales in 2016-17 compared to 856 in the North East. (Vector STEM Partnership (2018) CREST in Wales, Final Evaluation).
[14] Further Maths Support Programme
[15] Physics Mentoring Project
[16] STEM Gogledd

Stimulating Physics Network	With funding of £140,000/year from the Welsh Government, the Institute of Physics has delivered bespoke physics professional development support for non-specialist physics teachers since 2014. Currently 48 secondary schools across Wales are involved with 150 professional learning sessions scheduled. The programme aims to build confidence and is delivered in conjunction with the regional education consortia.
Swansea University-Cosmos Centre	Centre for Science/Maths dedicated classroom for schools to visit – focus is always on female participants.
Science for Schools Scheme (S4)[17]	Delivered by Swansea University since 2012. Since 2018 S4 has formed part of the pan-Wales Trio Sci Cymru Consortium, supported by the ESF and Welsh Government funding. S4 is currently running an intensive three-year program with over 500 young people from seven partner schools in South Wales. Each participant attends between three and six events every year on the University campus, further details of evaluation of the programme presented in Section 3.1.2.
Techniquest	Located in Cardiff[18] and on the Wrexham Glyndŵr University Campus[19] interactive science experiences are delivered. The Welsh Government's grant has experienced annual phased reductions since 2017 and is currently £650,000, with zero funding in 2021-22 requiring the charity to move to a more diverse funding portfolio.
Technocamps 2[20]	Swansea University manage this ESF (£3.8 million) and Welsh Government (£1.5 million) funded programme (£300,000/year (2019 and 2020); £150,000/year (2021 and 2022). Other partners are Aberystwyth, Bangor, Cardiff, Cardiff Metropolitan and Glyndŵr Universities and the University of South Wales. The project will work with 3,600 young people from across West Wales, North Wales and the South Wales Valleys, two-thirds will be female. The project will target secondary schools where computer science is not currently offered at GCSE, or where it has only recently become available. Further detail presented in Section 3.2.1. Technocamps has operated since 2003, received WEFO funding in 2011 – this four year project engaged with 8,700 participants.
Trio Sci Cymru[21]	Partners include – Bangor, Swansea, Aberystwyth and Cardiff Universities, with £5.7 million ESF funded and £2.5 million from the Welsh Government - 2019-2022 (3 years). Target - 5,600 young people aged 11-14 years from 30 schools (north and West Wales and south Wales valleys).
Welsh Valleys Engineering Project[22]	Fully funded by the Panasonic Trust, this five-year programme launched March 2018, is working in partnership with Coleg Gwent and The College Merthyr Tydfil, working schools across the Welsh valleys to deliver STEM teacher CPD and student support activities.

[17] Swansea University Science for Schools Scheme (S4)
[18] Techniquest Cardiff
[19] Techniquest Glyndŵr
[20] Technocamps
[21] Welsh Government (2018) £5.7 million EU funds to encourage STEM take up.
[22] Welsh Valleys Engineering Project

Figure 1.1. Examples of STEM projects in Wales



2. Methodology

This section sets out the methodology for the literature review, including a discussion of the review's key questions, scope and a description of the process.

2.1 Review questions and scope

The project's inception phase identified that the literature review should focus on examining evidence of the effectiveness of interventions relating to improving gender equality in relation to STEM at different intervention points (i.e. ages or life-stages). This included identifying evidence of the key intervention points which are likely to make the most impact within a reasonable timeframe. The primary review question is therefore:

- What evidence exists of the effectiveness of interventions to improve gender equality in STEM?

Secondary review questions are:

- At what age(s) or stage(s) are these interventions delivered?
- What are the outcomes and critical success factors of these interventions?
- What lessons can be learnt from these interventions?
- What interventions might potentially be implemented in Wales?

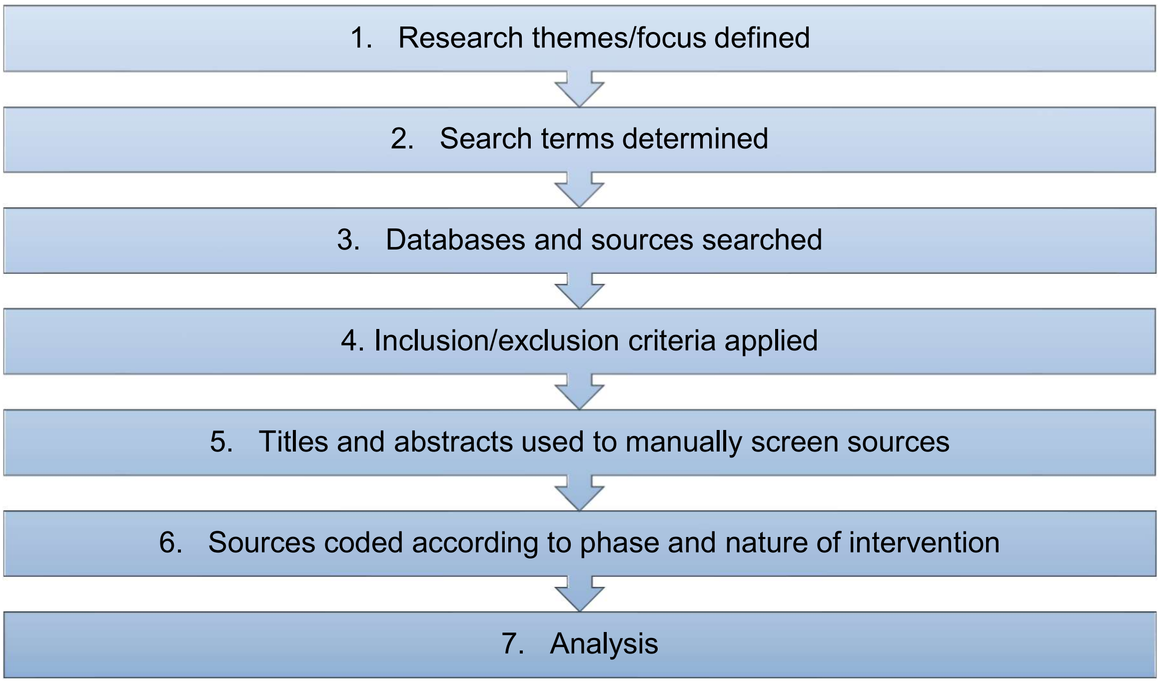
In terms of timeframe, recent evidence on interventions delivered regarding gender equality in STEM published in the last 10 years provided the scope for this review.

2.2 Overview of the approach

It is important to note that the scope of the review does not enable a Rapid Evidence Assessment approach to be used. However, in order to ensure that the literature review adopted a structured and balanced approach, some elements of a REA method were applied, for example identifying key research questions, developing key search terms and using defined inclusion and exclusion criteria.

The process for the review ensured that relevant high-quality sources were reviewed. Figure 2.1 presents an overview of the review process, with each stage of the process described in the following sub-sections.

Figure 2.1: Stages of the literature review process



Stage 1: Research themes/focus defined

During the inception phase of the project it was clarified that the literature review would focus on existing evidence regarding interventions delivered to support gender equality in STEM sectors or subject areas. Therefore, it was identified at an early stage, that the review intended to discover what has worked, when and how i.e. at what age are interventions delivered? What are their outcomes and critical success factors? This informed the development of the research questions (Section 2.1).

Stage 2: Search terms determined

The following broad themes and search terms (as well as key variants or sub-categories of these) were used to explore the literature;

> **Gender** – gender OR equality OR male OR female OR men OR women OR boys OR girls
>
> *AND*
>
> **STEM** – STEM OR Science OR Technology OR Engineering OR Mathematics OR Biology OR Chemistry OR Physics OR Medicine OR Computer Science OR Apprenticeship OR Social Science
>
> *AND*
>
> **Intervention** – intervention OR evaluation OR programme OR project OR activity OR participation OR enrichment OR outreach

Stage 3: Databases and sources searched

Key academic databases such as ProQuest[23] and Scopus[24], and the UK Research and Innovation (UKRI) Gateway to Research[25], as well as general web searches using Google and Google Scholar, and searches of specific academic journals were undertaken using the above search terms/strings, for example:

- Journal of Women and Minorities in Science and Engineering;
- International Journal of Gender, Science and Technology;
- International Journal of Science Education;
- International Journal of STEM Education;
- Physical Review Physics Education Research;
- Social Sciences.

Further searches were undertaken on organisation websites such as WISE, Institute of Physics and Equate Scotland. Searches were limited to the past 10 years and the English language, with academic databases also limited to peer-reviewed publications. An example of an extract from a database search is presented in Table 2.1.

Table 2.1: An example of a database search

Database	Search string	Results	Filters applied	Abstracts manually screened
ProQuest	ab(gender OR equality OR male OR female OR men OR women OR boys OR girls) AND ab(STEM OR Science OR Technology OR Engineering OR Mathematics OR Biology OR Chemistry OR Physics OR Medicine OR Computer Science OR Apprenticeship OR Social Science) AND ab(intervention OR evaluation OR programme OR project OR activity OR participation OR enrichment OR outreach) **Key**: ab – abstract	2,341	318	54

23 ProQuest is a large international multi-disciplinary database which enables access to 47 complete databases across over 175 subjects.
24 Scopus is a global abstract and citation database of peer-reviewed research titles.
25 Includes data from the following funding organisations: Arts and Humanities Research Council (AHRC); Biotechnology and Biological Sciences Research Council (BBSRC); Economic and Social Research Council (ESRC); Engineering and Physical Sciences Research (EPSRC); Medical Research Council (MRC); Natural Environment Research Council (NERC); Science and Technology Facilities Council (STFC); Innovate UK; National Centre for the Replacement, Refinement and Reduction of Animals in Research (NC3Rs).

Stage 4: Application of inclusion/exclusion criteria

Using inclusion/exclusion criteria, search results were filtered to focus on more relevant sources. For example, papers that focused on medical or health interventions were screened out by filtering search results using database categories. Sources were exported and recorded. At this stage, all sources that addressed the issues of gender equality in STEM were included, e.g. from the ProQuest database search 318 sources were recorded.

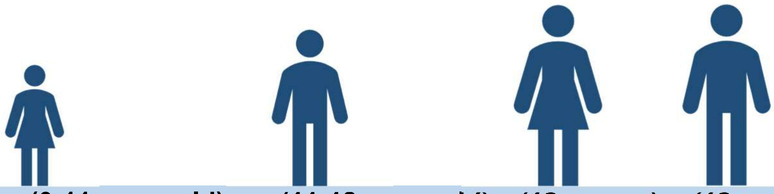
Stage 5: Titles and abstracts used to manually screen sources

As the focus for the literature review is the delivery of interventions, abstracts were used to filter sources further. It is important to note that although many studies explore gender equality in STEM many focus on the views of female and/or male school-aged learners, Undergraduate /Postgraduate students or individuals engaged in specific STEM-related careers. These sources were recorded for future reference, as the majority include conclusions which present implications that could be considered when considering future gender equality in STEM interventions. However, the delivery of interventions is the focus for this review, and abstracts were screened to identify those specifically focusing on the delivery and evaluation of a gender equality in STEM intervention, e.g. 54 sources from the ProQuest database search.

Stage 6: Sources coded according to phase and nature of intervention

As abstracts were manually screened and coded according to the education phase the intervention was delivered to. The nature and scale of the intervention, the STEM-subject focus, geographical scope and the methodology of the evaluation were also recorded if apparent in the title and /or abstract. Figure 2.2 presents the number of academic peer reviewed sources contributing to this review categorised by education phase. In total, it was possible to identify the education phase for 178 studies. However, it is important to note that some studies provided activities to participants across a couple of education phases and not all sources contained specific information regarding the specific age of the participants concerned.

Figure 2.2: Record of peer reviewed evaluations of interventions by education phase



Age range	(0-11 years old)	(11-18 years old)	(18 years+)	(18 years +)
Phase	Early Years and Primary School	Secondary School	Post 16 and Higher Education	Research and Employment
Number of sources	12	77	61	28
Geographical scope	US – 7; Australia – 2; Taiwan – 1; Germany – 1; UK – 1.	US – 46; Europe – 15 (incl. England (2); Wales(2)); Australia – 2 Canada – 2; Taiwan – 3 China – 2; Israel – 2; Hong Kong – 1.	US – 52; Europe – 4; Australia – 1; Taiwan - 1	US – 25; UK – 1; Ireland 1; Germany –. 1

Note: US – United States; UK – United Kingdom.
A small number of sources included reference to more than one education phase. However, the education phase may not have been clear and/or the geographical scope of the intervention was not stated in some sources.

Stage 7: Analysis of sources

During the early stages of the literature review an emerging findings summary was produced for the Welsh Government for Science based on the information contained in a sample of 100 abstracts. This review expands upon those emerging findings; the search was extended to include additional sources published since the first search in August 2019 and many peer reviewed academic papers have been explored in full, along with a more extensive review of the grey literature.

Once abstracts were coded at their education phase, the studies were analysed further to identify the type of interventions most frequently delivered, the research methodology used, scale of the intervention, and any learning points presented. This informs the findings in the following section. It is important to note that although a Rapid Evidence Assessment was not conducted, an indication of the robustness of sources is presented within the discussion, with reference included of the evaluation methodologies and the scale of the intervention. The scale of interventions varies, in a few instances small-scale studies are referred to if deemed appropriate to provide further supporting evidence or examples of activities.

3. Findings

This section presents the key themes that emerged during the literature review process. The findings explore the research on gender equality in STEM interventions by educational phase:

- Early years and primary school education;
- Secondary school education;
- Post 16 and Higher Education;
- STEM researchers and STEM-related employment.

Within each of the educational phases, a summary of the type of interventions delivered is presented along with any conclusions drawn by the evaluations. Examples are also discussed, with reference to any specific subject focus and the methodology used to conduct the evaluations, which also provides an indication of the robustness of the study concerned and the strength of evidence.

3.1 Early years and primary school education

The majority of the peer reviewed evaluations were delivered in the United States, with it recognised that any research focusing on gender equality and STEM in the early years and Primary education phase is limited in quantity (Sullivan and Bers, 2018, p. 1), as Figure 2.2 records only 6.7 per cent of the academic literature on evaluated interventions targeted at children in early years and/or primary school. Nevertheless, it is apparent that some of the evaluations applied robust research methods and all interventions concluded that strong benefits resulted, including improving opportunities and the interest of girls in STEM activities.

Key learning points

- Delivering activities using **interactive subject-specific** material (particularly robotics) has resulted in an increase in girls' interest in STEM
- **Inclusive, age-appropriate activities** for both boys and girls are recommended to avoid increasing gender stereotyping
- Sustaining an intervention over a **reasonable time** period (10 weeks) can be beneficial for participants
- Ensuring **preferred learning styles** are accommodated is important when planning and delivering interventions
- Exposure to **gender stereotypes** can contribute to gender differences in STEM
- Engagement with **role models** can positively impact girls' attitudes towards STEM

3.1.1 Subject-focused

Introducing coding and activities programming robots were the most frequently evaluated STEM intervention for this age group, with the activities developing skills and motivation for STEM. For instance, one American study tested the programming of robots to develop six-year-old girls' STEM motivation and examine stereotypes (96 participants). This study involved randomly assigned treatment and control groups – '**Girls given programming**

experience reported higher technology interest and self-efficacy compared with girls without this experience and did not exhibit a significant gender gap relative to boys' interest and self-efficacy' (Master et al., 2017, p. 92). This study also reported that 'girls who held stereotype views that boys were better than girls at robotics and programming also reported lower self-efficacy' (Master et al., 2017, p. 100). However, other key findings suggested that;

> *'gender differences in children's technology motivation are not set in stone; instead, they are malleable and open to influence from specific experiences […] providing positive experiences with technology to girls can lead to higher technology motivation.' (Master et al., 2017, p. 101)*

This evaluation also found that both boys and girls held the stereotype about boys being better than girls at robotics and was stronger than children's stereotypes about other fields. Even though the girls were more motivated to engage in technology, the intervention did not alter girls' stereotype views of computer programming. The evaluators also noted that for this particular intervention the activity was created to appeal to both boys and girls, with it proposed that activities should be **designed inclusively**, as this may increase interest from boys too. Alternatively, it was noted that by targeting female-only activities, by their very nature, they can increase gender stereotype and girls can be less interested if segregated (Master et al., 2017, p. 102).

Another similar American **robotics curriculum intervention** delivered to 100 children aged five to seven years old, which although it did not include a control group also concluded that a 'developmentally appropriate robotics curriculum can increase girls' interest in engineering' (Sullivan and Bers, 2018, p. 1). A previous similar investigation of a six-lesson robotics and programming curriculum found that 'boys scored significantly higher than girls in only two areas: properly attaching robotic materials, and programming using Ifs' with both boys and girls completing the programme successfully (Sullivan and Bers, 2013, p. 691). The researchers concluded that both boys and girls are equally capable of applying the concepts required and the success of these robotics interventions demonstrates potential for providing similar opportunities for younger children to explore computer programming. Another small-scale American study that observed coding skills during a week-long programme with 28 five to six year old children found similar results with the child's gender not related to outcomes and that children can successfully learn coding skills when the 'apps are appealing to children' (Pila, 2019, p. 52).

3.1.2 The length of time required

One American study delivered **a Science Literacy Project** intervention for five or ten weeks to five-year-olds in two schools. In this study, another school acted as the control group and received only regular Science content. Boys in the control group reported liking science more than the girls in the same class, whereas both boys and girls in the 10-week intervention reported equally that they had greater science competence than those on the five-week course (Patrick, Mantzicopoulos and Samarapungavan, 2009, p. 166). The study concluded that taking part in a **longer series of science activities** offers 'children multiple and interrelated opportunities to engage with science'; concluding that 'developmentally appropriate early science education' initiatives need to be encouraged (Patrick, Mantzicopoulos and Samarapungavan, 2009, p. 183).

All the above evaluations of robotics interventions with younger children provide evidence to support the delivery of longer-term activities and similar findings were apparent with older age groups, which are discussed later. Valla and Williams (2012) also emphasised that for primary school aged children encouraging interest in STEM is critical, with older students making decisions that 'have a substantial impact on their interest in pursuing STEM' (p. 27). The example below presents some impacts to result from a series of focused science workshops delivered by a Welsh university.

The Swansea University Science for Schools Scheme (S4)[26] – bespoke workshops

This scheme engaged 1,367 primary-school-aged children and 987 secondary-school-aged children in bespoke workshops over a single academic year, and even though only post-workshop data were collected, and in some instances samples were small for specific workshops, the programme's evaluation reported positive outcomes with the activities found to be 'equally effective for male and female pupils'. Yet, differences in the gender of pupils was more significant among secondary-aged learners, with males reporting higher levels of enjoyment as they recalled the more active learning activities, with females reporting on facts of information.

Although an immediate impact on career aspirations for primary children from deprived areas was reported, it was noted that they held a 'naive understanding of science careers' anyway. The scheme used an equal balance of male and female presenters to deliver activities, yet it was recommended that females needed to 'ensure that they present themselves as doers of science' (Bryan et al., 2019, pp. 32-36).

3.1.3 Accommodating different learning styles

Individual children learn differently, for example, some prefer to use pictures and images (visual), others prefer speaking and listening (auditory) whereas others prefer to use their sense of touch (physical/ kinesthetic). Prior to an Australian university's outreach programme for primary and secondary aged students the participants' **learning style preferences were collected** and the programme was designed to accommodate these – 'learning through practical activities, technology was reported as artefact and they preferred learning about biological or environmental sciences' (Little and de la Barra, 2009, 439).

Other studies have examined peer learning and learning through inquiry. For instance, one English study with 341 primary-aged children concluded that **peer collaboration** in science resulted in an advanced conceptual understanding for boys only (Leman et al., 2016, p. 176). Whereas an Australian programme (Makerspace) that targeted 71 female primary school students mentored by undergraduate students to complete STEM-based projects reported positive motivation from students to create, criticise and generate ideas – with **learning through inquiry** more prominent than conceptual learning (Sheffield et al., 2017, p. 161). These evaluations reflect the importance for those designing and delivering interventions to be fully informed regarding the preferences of their target group.

[26] S4 – Swansea University Science for Schools Scheme – university level science workshops and experiments.

Bringing Up Girls in Science (BUGS) was an **after-school activity** for 10-12 year olds in the US. The study collected follow-up data for 12 participants and contrasted findings with others engaged in STEM ('12 former BUGS contrasts, 10 college science majors, 10 non-science majors, and 9 current STEM professionals'). Participants of the after-school activity reported '**higher perceptions of science careers** than BUGS contrasts'. Although this is a comparatively small-scale study it does provide an example of the potential benefits of delivering content via an extra-curricular activity (Tyler-Wood et al., 2012, p. 46).

A study that involved more than 400 primary-aged children established that using interactive items affected speed and performance when completing tasks. Gender differences were reduced, and the **use of multimedia and interactive tests** are to be encouraged instead of paper and pencil as early as possible to 'enhance girls' potential in STEM participation' (Jeng and Lui, 2016, p. 206).

3.1.4 Role models

Science Made Simple[27] has delivered science shows and workshops to primary and secondary-school-aged learners across Wales since 2002, and the following provides an overview of the impact of these activities, which drew on role models to contribute to children's knowledge and understanding of the potential of STEM study and careers.

Science Made Simple

Evaluations of some of Science Made Simple's activities include a show featuring real scientists and engineers, with interactive experiments that toured 60 schools in 2013; the views of 363 students were collected to examine the impact of the show on attitudes towards STEM. It was reported that there was a larger increase in the proportion of girls who commented that they would like to work in STEM after experiencing the show (pre-show 10 per cent, post show 25 per cent), for the male participants the proportion interested before the show was 24 per cent, this rose to 35 per cent afterwards (Sadler, 2018, p. 3). There was also a larger increase in the use of positive words to describe scientists and engineers by the girls, with it concluded that attitudes shifted towards science being an attractive career (Sadler, 2018, p. 4).

An evaluation of the female-focused 'people like me' initiative (a range of workshops that explored personality types and related them to STEM) also reported similar findings, informed by 180 responses from 11-14 year old female participants (Herman, Kendall-Nicholas and Sadler, 2018, p. 16).

One study with 335 German children reported on the influence of the **exposure to stereotypes** as a contributing factor to gender differences in the STEM fields; concluding that there is some support that stereotype endorsements for both boys and girls can be affected by even short exposure to gender stereotypes (Wille, 2018, p. 1).

A recent £2.5 million funded partnership that engaged with 2,180 participants across the UK explored the role of informal science in youth work, with some projects including either explicit or implicit gender specific approach. Half of the projects' participants were younger than 10 years of age and 40 per cent aged between 10 and 15 years (Wellcome Trust,

[27] Science Made Simple delivers high energy interactive shows for schools and festivals across the UK, and has engaged with over 750,000 people since 2002.

2019, p. 7). The main expected outcomes that focused on development of self-belief and well-being were achieved, with it also noted that new STEM career aspirations emerged using the youth development approach to science (Wellcome Trust, 2019, p. 3).

It is perhaps surprising that research relating to gender equality in STEM interventions during the formative early years is limited, particularly when it is considered by some that most young people's views of STEM-related careers appear to be established by the end of primary school (Chambers et al., 2018, p. 3; Archer et al., 2013, p. 1).

The examples discussed above highlight clear positive outcomes for this age group particularly when interventions are delivered over a period of time (e.g. 10 weeks) as opposed to a one-off activity, and when interventions consider individual learning preferences, interests and the advantages of inquiry-based/collaborative tasks. However, other research proposes that there is a four-year opportunity to nurture females' passion for STEM subjects; a large project across 12 European nations collected the views of 11,500 females. It concluded that females are drawn to STEM subjects between 11 and 12 years of age, but this interest significantly falls at 15/16 years of age (Microsoft, 2018, p. 5). The following section presents the research on gender equality interventions delivered to this age group.

3.2 Secondary school education

Compared to the early years and primary school education phase examples, there is a wider geographic scope to the secondary education phase peer reviewed literature and more focus on this phase of education (43.5 per cent of the reviewed literature). Nevertheless, as with the early years and primary school education phase interventions, the majority of secondary school education interventions identified are US-based, with a few European examples. Studies do not always provide detail regarding the specific age range e.g. 11-16 (GCSE) and post 16/sixth form (A level) of an intervention. As a result, all evaluations are combined for the secondary school education phase in this section.

As previously mentioned, during early years and primary school education, the delivery of STEM activities is motivated to develop interest in STEM, whereas during secondary school the motivation shifts to ‘increasing achievement’ and maintaining the interest gained at the younger age (Valla and Williams, 2012, p. 29).

Key learning points

- **Practical subject-based** activities can positively impact female students’ views of STEM-related subjects
- A **non-stereotype classroom** environment can increase females’ interest in STEM subjects
- The **balance of male and female** students in working groups can influence outcomes
- An awareness of **gender stereotyping** for this age group have proved effective
- Learners’ **life experiences and interests** are important when determining the subject content and focus for interventions
- Real-life, authentic, **collaborative learning** approaches have proved successful in engaging females in STEM
- Interventions of **varying lengths and frequencies** (e.g. after school club, one week intensive/ residential, three months, year-long) can result in positive outcomes
- Mentoring females – **one-to-one, online or in groups** can help female students clarify their career aspirations
- Engagement with **role models**, over varying time lengths, can influence females’ views of STEM and stereotypes
- **Parents** also influence their child’s decision making regarding future subjects studied; delivering an intervention to parents can have a positive impact on children’s decisions

Specific examples of interventions for secondary school aged learners are discussed in this section, although some of the literature identified included reviews of several intervention programmes e.g. a systematic review of studies evaluating STEM intervention successes, which include those for school-aged students (Van den Hurk, Meelissen and Van Langen, 2019, p. 150).

Valla and Williams' study of school STEM intervention programmes identified the key elements that intervention programmes targeting STEM contained, these included:

- Individuals to monitor and guide students either individually or as group members;
- High quality instruction;
- Longer term investment to address stages of the STEM pipeline;
- Sensitivity to students' cultural background;
- Facilitation of peer-to-peer interaction;
- Financial support for visits/activities (Valla and Williams, 2012, p. 30).

Some of the above factors emerged during the previous section and they are also apparent in some of the detailed examples discussed here. It is also important to note that examination of systematic reviews, and other individual studies that examine motivation, experiences and barriers in relation to participation in STEM among females could prove useful to support understanding of any potential focus and content of future interventions (e.g. Reinking and Martin, 2018; Koul, Lerdpornkulrat and Poondej, 2016; Wang and Degol, 2013). Several studies identified in the secondary school education phase used PISA data[28] to examine cultural differences in gender and STEM subject performances and choices (e.g. Mann, Legewie and DiPrete, 2015). It is noted that recent PISA results for Wales have improved, with Wales performing at the international average in reading, maths and Science (Welsh Government, 2019, paragraph 139).

3.2.1 Subject-focused

Computing and robotics provided a popular route to motivate younger children and similar activities are also used with older children. However, the robustness of the research approaches applied in relation to evaluating these interventions varied. In one study, the short-term impact of a **game design** workshop with 21 female participants was explored using 'a pre and post application of a validated survey instrument, focus-group interviews, and content analysis of games developed by the students'. The study found that participants self-reported improvements in confidence and competence with computers (Akkuş Çakır, 2017, p. 115). Technocamps,[29] created by Swansea University in 2003, delivers an outreach programme using day-long workshops based on computational themes and provides support for schools to deliver extra-curricular clubs. The intervention has proved successful with 'many students opting to study computer science at Swansea University claiming to be influenced by Technocamps activities' (Crick and Moller, 2015, p. 1).

A couple of other studies focused on the **use of computer games** as a route to deliver science and attract more females to the subject. For instance, game construction was delivered to both male and female students during one Canadian project; reported outcomes 'were not male dominated' for higher order thinking, computer abstraction skills or enjoyment, with the researchers concluding that **game construction** is 'a viable gender-neutral' way to potentially increase female participation (Carbonaro et al., 2010, p. 1098). Another US study with 60 students reported that interest in **cyber science** increased for

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[28] PISA is the OECD's Programme for International Student Assessment. Every three years it tests 15-year-old students from all over the world in reading, mathematics and science.
[29] Technocamps has delivered over 1500 workshops to over 35,000 young people across Wales. Led by Swansea University there are University Hubs at Aberystwyth, Bangor, Cardiff, Cardiff Metropolitan, Glyndŵr and the University of South Wales.

females but not for males following an intervention programme (Turner et al., 2014). A further small-scale US study with 38 16 year olds who participated in cybersecurity activities revealed that '**single-sex collaborative settings**' contributed to an increase in the girls' interest in cybersecurity, and creative authentic learning activities helped to improve engagement (Jethwani, 2017, p. 3). Authentic learning experiences are explored in more detail in some of the following sections.

Another US study which delivered theory and project-based learning to 60 male and female students found that although the academic achievement for both sexes was similar, with motivation to engage in the **project-based activity** high, the girls' interest in scientific-technological subjects increased more than the boys' (Barak and Asad, 2012, p. 81). Using appropriate learning approaches are discussed in a later section in more detail.

One large-scale European study involved 1370 students from 60 secondary schools working with research institutions to use **climate change** to underpin **authentic learning experiences in science**. More female students believed they had learnt many new things with both males and females positively reporting the benefits of authentic activities such as 'hands-on experiments' (Dijkstra and Goedhart, 2011, p. 131). Another study used **energy-monitoring** as a basis for hands-on, inquiry based learning and the disposition of students towards STEM subjects in the experimental group became more positive than those in the comparison group, with the disposition of girls more positive than boys (Knezek and Christensen, 2019, p. 26). Another American study with 52 secondary-aged students discovered that by amending homework tasks to make them more 'contextually interesting' resulted in improved interest and motivation for students; it was also noted that females chose to select biology contexts more than males (Wheeler and Blanchard, 2019, p. 1).

An evaluation of several STEM-focused enrichment activities delivered by Engineering Education Scheme Wales[30] also reported its impact on girls' 'increased enthusiasm for, and awareness of, the practical application of STEM subjects - particularly engineering' (Glover, Harries and Jones, 2018, p. 438). Between 2015 and 2018 3,600 female students participated in a range of activities including 'Girls into STEM' activities delivered solely to females; 69 of whom were consulted, along with another 248 male and female students engaged in the other project activities. Another example from the UK involved secondary-school-aged girls training to become science ambassadors in primary schools, the activity was successful in developing 'a science identity' (Institute of Physics, 2017, p. 10). Physics provided the focus for another activity with 400 English secondary schools with inclusive teaching techniques (which included unconscious bias training for teachers), integrated careers and relevant work experience all credited with making physics more relevant to girls (Institute of Physics, 2017, p. 13). A project that linked these Institute of Physics interventions altogether across six schools in south east of England reported an increase from 16 to 52 girls taking AS level Physics over the two years of the interventions' delivery (Institute of Physics, 2017, p. 25).

[30] Engineering Education Scheme Wales has delivered engineering activities to students in Wales since 1989.

All the above findings link to those reported for younger children, where the type of activity delivered has an important influence on motivation and engagement. Yet, other factors such as the specific learning environment and addressing stereotypes in particular were also prominent in the literature.

3.2.2 The learning environment

While some of the research focuses on specific subject content, other American researchers have explored gender equality in STEM from a different starting point – the physical classroom environment where an activity is delivered. One study exposed 269 participants to alternative computer science **classroom environments** – one classroom not projecting computer science stereotypes and the other with noticeable stereotypical displays. The study's findings noted that girls, but not boys, in the non-stereotype environment expressed more interest in taking computer science than girls in the other classroom where there was stereotypical information (Master, Cheryan, and Meltzoff, 2016, p. 424).

How students are grouped for learning activities also influences the impact of the learning environment and an example based on Biology classes in Flanders for 496 14-15 year old students discovered that 'when girls collaborate they perform best within the same-sex groups, whereas boys achieve better results in mixed gender groups', such findings could be important for developing the optimal learning environment and help to tackle the gender gap (De Smet, 2016, p. 53). However, one American study examined the impact of interactions within different group dynamics for engineering contexts and it concluded that 'girls learned more in mixed-gender groups' (Schnittka and Schnittka, 2016, p. 1). The importance of **group dynamics** has also provided focus for researchers in post 18 education and is discussed in the higher education section. Immersing females in an environment with a specific STEM focus has also proved effective, as illustrated in the example of the potential of a residential work experience outlined below.

The potential of residential work experience and strong partnership working

An example of a successful careers-award-nominated residential work experience placement was that delivered at RAF Cosford for 24 young women aged 14-19, each year from 2009-2012. The evaluation of the project used follow-up surveys over a three-year period and included completion of the CREST Award as a measure of success. Young women needed to apply for the experience formally, a workbook was an integral element during the experience and provided structure for the activities.

The evaluation reported on the impact for 74 participants, which was 'overwhelmingly positive', and a significant number reported that they had been able to test a career idea and were able to clarify their career ideas for the RAF and engineering. **More than half of the participants reported moving into STEM courses or careers, and perceptions that a career in engineering 'would be 'dirty' was halved'**.

The delivery teams' relationship with other partners was critical for the success of the experience, along with well-established aims and objectives – a holistic approach proved successful (Collins, 2013).

3.2.3 Addressing stereotypes

The early years and primary school education examples focus on specific STEM activities, addressing stereotypes was not emphasised as much, whereas interventions targeting secondary-aged students provided examples of gender stereotypes incorporated into activities. Nevertheless, it is important to note that a pilot project delivered in Scotland worked with five school clusters, which included a secondary school, primary schools and in some cases early learning and childcare centres with the aim to bring about cultural change using an 'embedded and sustainable approach to tackling gender imbalance in subject uptake and education pathway choices' (Skills Development Scotland, 2018, p. 3). Two project officers worked with clusters to develop intervention programmes focusing on a range of activities including **unconscious bias training** for teaching staff. The evaluation of the three year project reported that project champions, partnership working and alignment with strategic objectives provided critical success factors for the project (Skills Development Scotland, 2018, pp. 18-20).

Addressing **gender stereotypes** also formed the basis for a mathematics study in China. Nine sessions were delivered over three months targeted at 'changing adolescent girls' collective representations, situational cues and personal characteristics'. Data was collected before, immediately after, and three months after the completion of the intervention. Findings collected immediately following the intervention noted that mathematics gender stereotypes were significantly reduced, with the follow-up data indicating that these outcomes were sustained, while also indicating no significant differences to the control group (Zhao et al., 2018, p. 612). Others support these findings, one three-year project reported that female students in particular 'experienced a positive change in perception of gender stereotypes' in Information technology (Forssen et al., 2011, p. 46).

Physics lessons provided the focus for a similar American study with 312 physics students were randomly assigned to three different stereotype threat (ST) environments – 'an explicit ST condition, an implicit ST condition, and a nullified condition'. Male responses to the physics problems were similar across the three environments; whereas females in the nullified conditions 'outperformed females in the explicit ST condition' (Marchand and Taasoobshirazi, 2013, p. 3050). A slightly larger scale piece of research (484 students) used a game intervention with secondary-aged and university students to question gender assumptions. Although the intervention had no effect on the university students for the school-aged students there was a positive impact with them 'less likely to describe a female professor as a man' (Freedman, 2018, p. 162).

The above examples signify the potential for interventions that target developing awareness among practitioners, parents and pupils of gender stereotyping for this age group. They also demonstrate the potential of designing interventions that target gender stereotyping in individual subject areas. However, although a relatively small American study of 148 female participants of SciGirls Connect2 programme found that although students' STEM identity significantly increased as participants' perceptions of other people recognising them as 'STEM people' improved, this is less likely as students get older. This study also reported larger gains in STEM identity resulted from the after school programme rather than the summer camp (Hughes, Roberts and Schellinger, 2018, p. 3).

3.2.4 Accommodating different learning styles

Accommodating an individual's preferred learning style was important for some of the early years and primary school education gender equality in STEM interventions discussed and also emerged as a theme for secondary-aged activities, with the delivery of interventions **outside of school hours** delivered to female-only groups providing focus for a few studies in this age category. One such Canadian study highlighted the importance of activities being **driven by participants' experiences** and views as opposed to coming from a direct academic base, that a 'two-way exchange' was important for girls to re-figure their experiences as science-experiences; and re-figure science to include girls' every-day experiences (Gonsalves, Rahm and Carvalho, 2013, p. 1068). However, it is important to note that the scale of this research was limited (six 17-18 year old students). Nevertheless, another very small study, which focused on four girls' engagement with a robotics challenge supported this view (Gomoll et al., 2016, p. 899); participants welcomed the opportunity to personalise their robots, and receive direct feedback from peers and facilitators – all provided important motivation for engagement in robotics.

A larger, more robust American study that used a randomised control trial to evaluate the impact of an informal science intervention for girls found that: 'A multivariate analysis of variance demonstrated that programme participants scored higher than their control group peers on weighted composite of post-programme affinity indicators'. These indicators were science interests, efficacy with science, science attitudes, and science identity; suggesting that the informal science programme positively impacted 'the formation of science identities and efficacy in girls' (Todd and Zvoch, 2019, p. 102). An intervention programme delivered to 70 16-18 year olds at a London school by the Institute of Physics also reflected the potential to combine **a range of opportunities** to meet individuals' preferred learning styles. The evaluation of the programme found that activities delivered outside of 'normal lessons' were the most popular (Institute of Physics, 2014, p. 14). Other researchers explored this further with 254 participants who attended an informal summer learning experiences at three American institutions over three years. It was reported that the experience had 'extended and deepened STEM content learning while providing opportunity and access to content, settings, and materials that most middle level students otherwise would not have access to' (Roberts et al., 2018, p. 1). Evaluators of a STEM enrichment programme that has delivered to female teenagers since 2000 in the United States uses after-school and summer holiday activities to explore science and engineering, reported that activities 'must hold their interest, be fun, and not "feel like school."' (Mosatche et al., 2013, p. 24).

Another large-scale study with 1,848 American students across 29 schools also concluded that '**collaborative hands-on activities**' contributed positively to students' engagement in science (Bae and Lai, 2019, p. 1). A German study reported similar findings having investigated a range of engagement activities, the study concluded that 'different kinds of hands-on STEM engagement activities are likely to foster or maintain positive STEM dispositions', and when the impact on STEM dispositions was examined between genders no significant differences resulted (Christensen, Knezek, and Tyler-Wood, 2015, p. 898; p. 908). Another study in Taiwan with 72 secondary-aged girls also reported the benefits of **project-based group activities** to develop females' views of STEM (Lou et al., 2014, p. 52). Others also report on the potential for blended learning to spark girls' interest in STEM (Pinkard, 2017, p. 477).

A physics education programme in Hong Kong used a theme park to provide community-based science learning for 200 secondary-aged students and found that the innovative use of digital technologies resulted in 'traditionally large gender differences in physics performance and interest of learning are mostly eliminated'. Thus providing further evidence of the importance of practical, real-life projects.

3.2.5 The length of time required

The **length of time of interventions** was identified as an important factor for those targeting early years and primary school learners and this was also the case in the literature relating to secondary school interventions. One American study that delivered a STEM-focused careers intervention to 88 secondary-aged females over a nine week period reported that participants in 'the treatment group improved significantly on variables of career decision self-efficacy and STEM self-efficacy and increased those gains at three-month follow-up' (Falco and Summers, 2019, p. 62). However, other interventions delivered more intensively over a shorter timescale (one week) also report improvements in attitudes towards science and science-related careers, engineering careers and chemistry (Kim, 2016, p. 174; Cloutier, 2018, p. 18; Levine et al., 2015, p. 1639); with some activities delivered as a full-day outreach activity also significantly changing participants' attitudes to the applicability of science and interest in a scientific career (Levine, and Discenza, 2018, p. 1316). However, one study that involved 500 Israeli male and female students participating in science enrichment activities reported the girls displayed 'decreased interest in and lower self-efficacy toward physics', concluding that the intervention's design required improvement (Sasson and Cohen, 2013, p. 718).

Mobile exhibitions also provide opportunities for students to engage in STEM, and a large scale study (1,210 students) across four European nations which examined attitudes and motivation towards engineering, reported clear differences between the genders regarding views on activities such as designing computer games and animations – boys were keener, nevertheless knowledge improved for all students after the visit (Salmi, Thuneberg and Vainikainen, 2016, p. 638). The following provides an example of the processes involved to deliver an intensive STEM experience and although targeting students with existing 'science capital', it demonstrates the effectiveness of this focused approach, but is highlighting the type of programme that is effective for those already engaged.

Delivering a Physics Outreach Programme

Physics of Atomic Nuclei Program (PAN) – is an intensive week-long summer experience for American students, including lectures and laboratory experiments and research. A formal application process is required, including teacher references; 24 students (equal numbers of male and female) participate each year. As the programme was more widely advertised the selection process needed to become more stringent. The programme's evaluation included a matched comparison group and findings noted that participants reported an increase in the influence of the programme on their interest in STEM careers.

Although the participants were already competent in Science, due to the selective nature of the programme, they valued interaction with university staff and graduates and the authentic research experience.

Participants of PAN were almost **nine times more likely to study a STEM degree** and eight times more likely to want a STEM career than the control group of students (Constan and Spicer, 2015).

The longest timescale of an evaluated intervention in the literature was one delivered over three years, with **a range of activities** combined - summer camp, Saturday Academies and mentoring available, which aimed to encourage 117 female teenagers to pursue scientific careers in drug and alcohol research. Analysis five years after completion of the programme reported that;

> *'[..] program participants had greater confidence in their abilities to learn science and to complete the training for science compared to non-science careers. Participants were also more likely to attend college and to major in science than non-selected applicants. Finally, intervention participants were more likely to have retained their original aspirations for a career in science.' (Schumacher, 2009, p. 303)*

It is evident that resources and time available determine the length of an intervention. Nevertheless, it appears that although interventions vary regarding this they all result in impact, but by their very nature interventions that have required more expenditure and time have been evaluated to a greater extent, and potentially present more robust findings.

3.2.6 Mentoring

Some programmes focused solely on interventions which provided **mentoring** support to females. One large scale German evaluation with 1,237 participants included control groups which comprised of applicants that had been randomly selected for later participation (waiting-list control group) as well as a female and a male control group. This evaluation concluded that 'participation affected positive changes in certainty about career goals (independent of STEM) and in the number of STEM activities' (Stoeger et al., 2016, p. 53). An earlier German **online mentoring** programme with 312 participants used a comparable method to evaluate and reported similar findings (Stoeger et al., 2013, p. 408). A later German study went on to explore the differences between group mentoring and one-to-one mentoring; 156 female students received group mentoring, while 191 received one-to-one support from female academics over six months. The study discovered that the **group mentoring** was more effective regarding the amount of STEM communication, networking, increase in STEM expectations and students' roles within their STEM networks (Stoeger, Hopp and Ziegler, 2017, p. 394).

One small-scale intervention delivered to secondary-aged students in Wales resulted in mentors supporting improvement in confidence in the student's approach to STEM (Watermeyer, 2012, p. 679). Another six-week STEM careers intervention delivered to 68 students in England, also reported similar findings regarding outcomes such as a positive impact on broadening understanding of the jobs that science would be useful for. An American study also reported similar findings following a year-long after school mentoring programme delivered by female university engineering students to secondary-aged students; a significant correlation was reported between the quality of the mentoring and confidence in mathematics (Holmes et al., 2012, p. 137).

A more recent mentoring programme's evaluation that specifically focuses on the uptake of Physics and women in STEM is discussed below.

The Physics Mentoring Project - Wales

The School of Physics and Astronomy, Cardiff University is currently leading this Project, working with five other Welsh universities.[31] Mentoring sessions are delivered by trained undergraduate and postgraduate mentors to secondary-aged students in years 10 and 11. The project delivered to 87 year 10 and 11 mentees (52 per cent female) from nine schools using 21 mentors. As part of the baseline evidence gathering for the project, a survey of 1,000+ students (all Year 10 and 11 students in the mentees' schools) was undertaken to collect data on student intentions, attitudes and aspiration from all students.

An interim evaluation of the delivery and impact reported a statistically significant result for female mentees expressing a more positive attitude to studying for A Level Physics after participating in the Project - before taking part 8.8 percent of female mentees reported that they probably would take A Level Physics, after completing the mentoring this rose to 13.6 per cent, and 33.3 per cent reported they intended to have a STEM career before the Project, rising to 52.6 per cent after completion (Thomas and Rushton, 2019, p. 2).

Participants were positive about the Project, enjoying the engaging sessions and developing their knowledge of the subject and potential careers. However, teachers reported that targeting Year 9 students (before they complete their Science option choice) may be more effective (Thomas and Rushton, 2019, p. 15).

However, it is important to note that others report that 'student aspirations may be extremely resistant to change and intervention', nevertheless, the message that science is useful for careers in and beyond science is needed (Archer, DeWitt and Dillon, 2014, p. 35).

3.2.7 Role models

Evidence in the literature includes interventions that provide exposure to appropriate STEM **role models** for this age group and older. For example, one study in Israel involved 60 participants plus 30 in a control group, and involved participants visiting a high-tech company and meeting female scientists. The effect on students' perception of scientists and engineers, students' capability of dealing with STEM, and future career choice were explored. Findings indicated that participants respected scientists, yet significant negative changes were reported regarding their perceptions of female scientists and STEM career choices with further investigation proposed (Bamberger, 2014, p. 549). This type of intervention has implications for the length of time devoted to a programme, as depending on the nature of the intervention (such as a visit in this instance) there could potentially be differences in short and longer-term impacts.

One small case study example that examined a range of STEM activities delivered to learners in Wales noted that one successful outcome involved some participants acting as role models for younger females following their engagement with the programme, thus delivering impact over a longer time period (Glover, Harries and Jones, 2018, p. 432). A

[31] Physics Mentoring Project – Undergraduate and Postgraduate students from Aberystwyth, Bangor, Cardiff and Swansea Universities and the University of South Wales are trained as mentors and work with 14-16 year old students to increase confidence in science and explore physics-related careers and education.

similar small-scale European study that involved 15 students working with a scientist during an 11-week investigation found that the role model and the project-based nature of the intervention resulted in;

> *'the students reconstructing 'their stereotypical views of scientists and the nature of their work owing to their personal engagement in the investigation and their collaboration with the scientist.'*
> *(Avraamidou, 2013, p. 90)*

Others also reported that viewing a female role model as personable and engaging in 'authentic science' were key for students, rather than 'gender matching between role model and students' (Conner and Danielson, 2016, p. 2414). Other interventions substantiate the importance of female role models; for instance, girls encouraged to write about a role model tended to have 'stronger role model identification' and a 'sense of fit in science' compared to a control groups' response (O'Brien et al., 2017, p. 301).

A long running Australian STEM intervention programme that works with partner universities and schools reported on the delivery of 53 programmes since 2008 to more than 2,000 students, found that that 90 per cent of female participants continued with science into year 12. It was also noted that the programme used 'immersive, authentic experiences', with research integrated into the activities (Scott-Parker and Barone-Nugent, 2019, p. 6).

A large-scale intervention with students in France involved young **female scientists** delivering an hour-long activity, which provided information on science-related careers and specifically the under-representation of women in science. The facilitators also discussed their own experience and career path. Approximately 10,000 students were randomly selected for the intervention, following which students completed future subject choices, with it reported that following the activity there was an 'increased female representation from 30 to 34 percent in STEM selective tracks, and from 28 to 31 percent in male-dominated tracks'. However, it was also noted that the reduction in the gender gap only occurred with students who had a 'strong academic background' and had selected Science in 'high school' (Breda et al., 2018, pp. 4-33).

3.2.8 Intersectionality

While exploring the literature on gender equality and STEM it is apparent that some studies focus on **ethnicity, and /or socio-economic background** too. One study explored the perceptions of Black girls who participated in a community-based STEM programme. Although the scale of the study is not clear, the findings indicated that interest in STEM increased throughout the course of the programme and provided 'a more holistic approach to STEM learning that occurs across settings and over a lifetime' (King and Pringle, 2019, p. 539). Another study that focused on ethnic minority females' engagement with science found similar results during a four-week lunchtime intervention; 'when the girls were given opportunities to engage their personal narratives, and when science was open to critique, ethnic minority girls leveraged common historical narratives to build science narratives' (Thompson, 2014, p. 392).

The above findings reinforce those in the studies highlighted in Section 3.2.4, namely the importance of ensuring individual interests and circumstances are catered for during the planning and delivery of interventions. However, one three-year intervention in the US that aimed to engage females in studying engineering concluded that for ‘lower-income minority women’ having an interest in engineering was not enough for them to study the subject; as ‘a lack of financial resources and social support for engineering, as well as fears of failure’ negatively impacted their ability to pursue the subject (Bystydzienski, Eisenhart, and Bruning, 2015, p. 88). Such findings identify the potential to explore the intersectionality of gender in STEM further, along with considering other barriers that are reported to exist for females studying or working in STEM.

The S4 – Swansea University Science for Schools Scheme previously mentioned also addressed opportunities for those living in more deprived areas. Researchers noted that ‘pupils with presumed low educational capital showed greater positive impacts of STEM activity participation than those with higher educational capital’, and that there is no ‘poverty of aspiration’, yet learners were aware of barriers linked to socio-economic realities (Bryan, Gagen and Bryan, in review). Therefore, recognising that the nature of the interventions will influence the types of learners who are likely to be engaged, it is important to ensure that learners without science capital are positively involved

3.2.9 Other influences

All the above examples focus on the impact that direct interventions have on females’ attitude towards STEM subjects and careers during their time at secondary school. However, it is important to note that **other factors can influence motivation** and aspirations. One randomised experiment discovered that a **parental intervention** was ‘most effective in increasing STEM course-taking for high-achieving daughters and low-achieving sons’ but did not help low-achieving daughters (Rozek et al., 2015, p. 195). Another intervention which promoted STEM courses to parents via brochures and a website also resulted in a higher take-up of extended STEM courses for the intervention group than that of the control group during the final years of compulsory education (Harackiewicz, et al., 2012, p. 889).

As noted at the beginning of this section, the evidence suggests that the window of opportunity is limited regarding influencing female views and intentions to pursue STEM subjects or careers. The research suggests that school is the ‘critical stage’ for career choices (WISE, 2019, p. 8). The above examples highlight a range of approaches that have been trialled, all of which appear to produce positive outcomes regarding addressing gender-STEM stereotypes and developing female interest in STEM.

3.3 Post 16 and Higher Education

This section describes the evidence relating to gender in STEM interventions identified at post 16 and in the Higher Education (HE) sector. Evaluations of interventions for this phase comprised of 34.3 per cent of the academic studies examined, with American studies again dominating, a small number of European studies are also discussed. Within HE, research conducted with undergraduate students was most frequently identified in terms of gender in STEM interventions. Postgraduate students, engaged in direct research are included in the next section, and combined with the literature examining interventions that target those in employment. It is important to note that some of the interventions delivered to other age groups are developed and delivered by those working or studying in the HE sector. It has also been highlighted that rigorous tested interventions are not that common (Dennehy and Dasgupta, 2017, p. 5964). As mentioned previously, there are systematic reviews of intervention evaluations that also provide useful information regarding the effectiveness of interventions (e.g. Lee, Alston and Kahn, 2015; Van den Hurk, Meelissen and Van Langen, 2019). Some of the interventions summarised in these sources are explored directly in this section.

Key learning points

- **Project-based**, authentic subject-specific activities can positively impact female engagement in STEM
- Using positive media portrayals of females in STEM and implicit affirmation training can contribute to improving females' perceptions of these types of careers and developing **'a sense of belonging'**
- The support of a **female mentor** improves retention rates of women in STEM subjects
- Using an **online/ virtual learning** environment to deliver STEM subject content can encourage more female participation and **increase diversity** on courses
- Exposure to gender **stereotypes** can negatively impact females 'sense of belonging' to a STEM profession
- **Peer-led** tutoring and **small group** working have proved successful
- **Short/ limited interventions** can positively impact women's engagement in STEM
- Teams composed of **multiple female members** as opposed to dividing females between teams can improve performance
- **Single-sex STEM programmes** have the potential to increase females' sense of belonging
- **Multiple factors** influence female engagement with STEM subjects and STEM-related careers
- Interventions that focused on **female confidence** and reducing test anxiety can result in a positive impact on females' performance in STEM subjects

3.3.1 Subject-focused

Both the previous sections presented interventions that had successfully targeted specific subject areas to deliver their activities and those studying at university have also experienced similar activities. By this stage students have specialised their focus for study and some institutions have tried to maintain motivation and interest in STEM by delivering **‘project-based learning’**, thus providing a more authentic learning experience. For example, 492 natural science and engineering students at an American university engaged in at least one project-based learning activity during an academic year. It was found that the project positively ‘affected student perceptions of STEM skills, perceptions of the utility value of participating in STEM courses, and STEM career aspirations’. The evaluation also reported equal results regardless of gender and race (Beier, 2019, p. 3).

3.3.2 Addressing stereotypes

Addressing stereotypes via an intervention provided focus for a few studies for secondary-aged students (see section 3.2.3) and similar projects have been delivered to university students. One American university conducted a study using positive media portrayals of women in computer science (347 students consulted) to explore the effects on male and female students. The study found that being exposed to positive news stories about female computer scientists appeared to make no difference to men’s interest in the subject, but women who read about female computer scientists subsequently ‘expressed more interest’. The study concluded that stereotypes could be addressed through **media efforts** to alter how computer scientists are depicted (Cheryan, 2013, p. 58). A smaller Polish study with 50 students experimented in manipulating gender differences and found that by ‘highlighting similarities between men and women’ it could encourage them to engage in STEM (Jasko, Dukala and Szastok, 2019, p. 473).

A randomized-controlled trial, that tested interventions aimed at mitigating the effects of the “chilly climate” women may experience in the male dominated STEM fields were reported to have a positive impact. ‘Affirmation training’ helped women develop external resources and manage stress that can arise due to social marginalisation; and the ‘social-belonging’ intervention helped with integration into engineering, with both of the interventions linked to improvements in achievement and attitude (Walton et al., 2015, p. 468).

Another experimental study that involved 750 students in an American university’s Chemistry department reported that when women were exposed to bias, they ‘anticipated more discrimination and projected less sense of belonging, but when the participants read about an unbiased department the ‘gender difference vanished’. However, the researchers also noted that the findings were unaffected by the completion of diversity training ‘suggesting that knowledge of diversity initiatives alone cannot close STEM gender gaps’ (Moss-Racusin et al., 2018b, p. 651). This suggests that the delivery of unconscious bias training needs to be part of a package of initiatives targeting gender equality.

3.3.3 Mentoring

Evidence identified in section 3.2.6 found that **mentoring interventions** were effective with secondary-aged learners, and findings suggest that this is also the case in HE. A longitudinal peer-mentoring intervention at an American university with 150 students reported that:

> *'Female (but not male) mentors protected women's belonging in engineering, self-efficacy, motivation, retention in engineering majors, and post-college engineering aspirations [and] the benefits of peer mentoring endured long after the intervention had ended, inoculating women for the first 2 years of college—the window of greatest attrition from science, technology, engineering, and mathematics (STEM).'*
> *(Dennehy and Dasgupta, 2017, p. 5964)*

Another American university's mentoring programme reported similar positive findings, based on providing **'informal mentoring'** for first- and second-year female STEM students. The study involved 116 students across seven institutions and used propensity score matched research design (i.e. matching students who participated in the intervention to others with similar characteristics who did not) to evaluate the programme. Impact on female participants included:

- larger networks than their matched controls;
- strengthened scientific identity;
- increased interest in earth and environmental science career pathways;
- improved scientific persistence intentions as a result of strengthened scientific identity development (Hernandez, 2017).

Others have conducted studies that supported the positive impact of an allocated female mentor e.g. a study of 72 undergraduates who interacted with a female subject expert 'showed more implicit identification with math, and increased their effort on a very difficult math test compared with others who interacted with an advanced male peer'. Similar results were presented for 101 engineering students, highlighting the benefits of exposure to 'same-sex experts' to improve women's **sense of belonging** and 'connectedness' (Stout, 2011, p. 268).

A smaller scale American university mentoring programme (17 participants) produced similar findings including: that women were more comfortable with **female mentors;** that male students had a greater affinity with the masculine-dominated culture of STEM; and that females sought the support of same gender mentors to 'mitigate some of the discomforting aspects of their STEM research experiences' (Daniels et al., 2019). Another American study that supported females with mentors found that women believed they were weaker than men at admission to university even though their academic performance was similar. Yet, by the time they reached graduation the women reported their 'self-efficacy was equivalent to men's' having engaged in the mentoring programme (MacPhee, Farro and Canetto, 2015, p. 2013, p. 347). **E-mentoring** has also been employed to support females studying STEM who were located in more rural or remote areas of a country (Australia) (Redmond and Gutke, 2019).

3.3.4 The learning environment

Some of the above mentoring interventions required students to have online access to learning, and other research has focused on delivering the subject matter using an **online / virtual learning environment**. For example, a study of 56 learners at one German university concluded that delivering female-only courses would improve female under-representation on engineering courses (Christophel and Schnotz, 2017). An American university employed a similar approach to deliver STEM to a wider group of students and reported that the programme was successful in 'increasing diversity'. This study found that the programme provided a 'viable route in the myriad of STEM pathways', with the course having **greater diversity** than the on-campus route - 71 per cent of the students were female (Drew et al., 2016). Another intervention used online delivery to enable a female role model to interact with 68 Chemistry students and 252 Psychology students. 'Relative to the control group, the intervention group had higher grades and lower failing and withdrawal rates' (Herrmann et al., 2016, p. 258).

The impact of the physical environment on gender-STEM stereotypes has already been highlighted for younger age groups and one American university explored the impact of this further, investigating the effects of a '**welcoming environment**' compared to 'a traditional STEM environment'. This study found that 'Women in the welcoming environment received more messages about women in STEM, were more likely to wear or carry markers of their major and had more peer role models in STEM'. Consequently, by manipulating the environment to decrease stereotypes female STEM identification increased (Ramsey, Betz and Sekaquaptewa, 2013, p. 377). Another experimental study with 193 students supported these findings, concluding that 'less stereotypical contexts' needed to be created to have a positive impact on females continued engagement with STEM subjects (Schuster and Martiny, 2017, p. 40).

Delivering support for students using **peer-led initiatives** has also been explored as a route to improve achievement and retention on STEM degrees. For example, one US university's 10-year study reported positive outcomes, particularly among female students (Drane, Micari and Light's, 2014, p. 210). Providing encouragement and working with peers was the focus for another American study with 168 men and 285 women, who 'were randomly assigned to receive an email invitation to a **peer-led tutoring** programme that included factual information (control group), growth messages, or culture-matching growth messages emphasizing effort and interdependence'. Findings reported no impact on the men who signed up to the tutoring sessions, whereas 'growth messages increased women's sign-ups'. Consequently more women attended sessions and achievement improved (Covarrubias, Laiduc, and Valle, 2019, p. 434).

A similar US university study explored the impact of the proportion of male and female engineering students during small group working. The experimental design varied the composition of groups to include 75, 50 and 25 per cent females. There was a greater impact for first year students with female students in 'female-majority and sex-parity groups' reporting less anxiety than those in the female minority group. However, this did not apply for more advanced students. Nevertheless, conclusions promoted the use of **small group working** to keep females engaged (Dasgupta, Scircle, and Hunsinger, 2015, p. 4988). Similar positive results were reported by a study with 369 students that examined the impact of an 'advising alliance' for women using a control group; it was reported that ‘instrumental support and psychosocial support are two salient factors for women in STEM’ (Primé et al., 2015, p. 64).

One American university experimented by offering an altered grading system for students (Successful/Unsuccessful Grading) to see whether this had any impact on retention, and if there was any differential impact for under-represented groups. There was a control group of 837 students which consisted of students who decided not to take part, with 651 students selecting to participate. Although the project reported positive impact, this was primarily for ‘non-minority males’, with the gains for females reported as too small for any certainty (Novak, Paguyo and Siller, 2016, p. 103). Other elements of the HE learning environment are discussed later with group dynamics and other priorities such as approaches to assessment /exams which reported interesting findings.

3.3.5 Role models

Exposure to **role models** as a tool to influence female views of STEM was highlighted in some of the interventions aimed at secondary-aged learners and has been employed in HE too. For example, one American university exposed 72 female STEM students to a female role model twice, with more positive outcomes of relating to STEM reported by the students who engaged in **reflective practice** following the exercise (Camp, Gilbert and O'Brien, 2019). A similar study used a ‘counter-stereotypic video intervention’ to investigate gender gaps in verbal participation during group discussions by 143 mixed-gender STEM students. Following the intervention men spoke longer than women in the control condition; having viewed a stereotypical discussion, where men dominated the input, but men and women spoke for equal time in the intervention condition group; their video had presented equality of input by both genders (Lewis, Sekaquaptewa, and Meadows, 2019, p. 557).

Other studies also reported similar successes as a result of **short role model interventions**. For example, when 100 undergraduate students engaged with female and male computer science role models for a very short time (two minutes) it was reported that exposure to ‘the stereotypical role model had both an immediate and an enduring negative effect on women's interest in computer science’; women experienced a ‘reduced sense of belonging’, as a result of the role model fitting current stereotypes regardless of whether they were male or female (Cheryan, Drury and Vichayapai, 2013, p. 72). Another similar study with 72 female STEM students, who met with a female role model on two occasions found positive outcomes regarding STEM course participation (Van Camp, Gilbert and O’Brien, 2019, p. 649).

3.3.6 The length of time required

Interventions discussed above vary in the level of engagement required and positive impact was reported by a large randomised controlled trial study involving 3,945 students that explored the impact of a **“low dose” intervention** – two personalised emails to encourage application to an applied statistics conference. The study found that the intervention resulted in a robust, positive effect and the evidence suggested that that women responded more strongly than men. However, some limitations of the approach were identified; for example, other underlying disparities between the genders were exposed during the study, as females’ ability to obtain supporting letters for application was lower (Unkovic, Sen, and Quinn, 2016).

One way of engaging females with STEM role models is during **visits** to support the delivery of the curriculum. Interventions targeting life experiences were identified during the secondary-school aged discussion (See Section 3.2.4), and one similar intervention was identified in the HE sector. This study reported positive outcomes among 375 female students who visited Science and Technology professionals and took part in the delivery of context-based science and technology content. The study reported that female participants 'maintained relatively positive attitudes towards science and technology', while the attitude of females not involved in the intervention 'declined significantly' (Machina and Gokhale, 2010, p. 523).

3.3.7 Group dynamics

Whether courses or working groups succeed more when they are single sex or include both genders has been discussed previously, and the **gender composition of learning /working groups** has also been investigated specifically. One study that varied the proportion of female group members for two Biology courses discovered that as the proportion of women increased in a group, all student performances improved regardless of gender (Sullivan, Ballen and Cotner 2018). Another study explored 95 women's sense of belonging and examined the impact of the gender balance of teams. Findings emphasised that teams should be 'composed of multiple women versus an approach that divides women up among various teams' (Niler, Asencio and DeChurch, 2019, p. 1).

Delivering a **female-only STEM programme** has also been explored as a route to improve women's sense of belonging and consequently continued engagement with STEM. One study examined this type of intervention with 65 students concluded that a 'greater sense of belonging' was reported as a result of 'perceived identity compatibility, perceived support from close others, and perceived support from the single-sex program' (Rosenthal, 2011, p. 725). An American co-educational STEM-Living/Learning intervention reported similar findings using data gathered over three years. This study found positive links between the programme's input and participants' professional expectations regarding job prospects and success for women (Szelényi, Denson and Inkelas, 2013, p. 851; Szelényi and Inkelas, 2011, p. 349). A small German study with 30 students delivered over a single day also reported positive outcomes when same-sex groupings of physics students were adopted and content delivered that acknowledged women's interests. This study reported positive impact on physics identity constructs. It was noted that although improvements in interest and competence were reported by the female participants there was no effect on male participants (Wulff et al., 2018). Another experimental study found that when women perceive they exert more effort than men to succeed there is a decrease in their sense of belonging and motivation; but when the effort expected was emphasised as normal this 'elevated women's feelings of belonging and future motivation' (Smith et al., 2013, p. 131).

3.3.8 Intersectionality

Gender, STEM, ethnicity and socio-economic background emerged as a theme for interventions focused on secondary-aged learners (see section 3.2.6) and there is evidence of similar research with undergraduate students. For instance, one study found that Black women who learned about Black professors, providing an 'identity-safety cue', reported 'greater anticipated belonging and trust, relative to those learning about a White man or a White woman professor' (Johnson et al., 2019, p. 131). A similar experimental study with 199 females reported that females from the under-represented ethnic minorities, who were educated 'about the harmful impact of gender stereotypes' and provided with strategies to cope with stereotype threat, achieved higher end of year grades than their counterparts in the control group, with the intervention having no effect on White participants (O'Brien et al., 2019).

Another American enrichment programme (Hopps Scholar) also addressed the gender equality agenda with focus on increasing the participation of black males in STEM. The extensive programme involved an eight-week summer course, mentored research, coaching and counselling, and financial assistance to support fees and travel while studying at undergraduate level. The evaluation of the programme included comparisons with other similar enrichment programmes and noted the additional elements of visits and tours to the laboratories were influential for participants, with it concluded that 'Hopps Scholars were significantly more likely than non-Hopps STEM graduates both to pursue STEM doctoral degrees and to attend doctoral-granting institutions with higher research activity' (Thompson et al., 2016).

3.3.9 Addressing other priorities

A few interventions focused on **improving females' confidence** in their ability to achieve in physics, maths and biology. A randomised double-blind intervention with 399 physics students focused on 'values affirmation' and found that 'benefits were strongest for women who tended to endorse the stereotype that men do better than women' (Miyake et al., 2010, p. 1234). Female mathematics students' test performance improved in an experimental group (122 participants) that had received a balanced view of women's representation in STEM (Shaffer, Marx and Prislin, 2013, p. 454). An intervention with 1,140 biology students focused on **reducing test anxiety**, with positive outcomes reported for both male and females as test scores improved, yet women were more likely to share their anxiety about tests. It was concluded that multiple factors influence female under-performance in biology (Harris et al., 2019).

Another American university's study of more than 1,000 Biology students across nine courses, examined the impact of different approaches to assessment; including 'high-stakes exams [..] group participation […] and in-class activities'. It was found that;

> *'Females underperformed on exams compared to their male counterparts, a difference that does not exist with other methods of assessment [it was reported that] the shift away from an exam emphasis consequently benefits female students, thereby closing gaps in overall performance.' (Cotner and Ballen, 2017, p. 1)*

It was noted at the beginning of Section 3.3 that universities are involved in many of the interventions delivered to the younger age group, and by the very nature of the research element of their work staff are also the prime actors in research in this field. Consequently, the following section explores the evidence of interventions delivered specifically to researchers and those in STEM-based employment.

3.4 STEM researchers and STEM-related employment

Doctoral and Postgraduate research are also areas where gender imbalance exists. As with the earlier stages in education, there are studies that explore the barriers for females in STEM. However, studies that interrogate the effectiveness of delivered interventions are limited; 15.7 per cent of the academic papers reviewed targeted this phase. Although there are some interventions reported that target females in STEM employment, the majority focus on those employed in academic institutions, (and likely to have worked through the research route), therefore these are combined for this section.

Key learning points

- WiSER[32] and WIMHS[33] are examples of **established mentoring programmes** that successfully focus on individual STEM subjects or STEM as a whole and gender
- Gender in STEM intervention programmes available for some higher education research/staff have been **evaluated over several years**
- The delivery of **career development programmes** can positively impact the retention of females
- **Goal setting** provides a critical element for female mentoring programmes
- **Video interventions** can reduce gender bias and increase awareness of the issue, yet it is noted that tools need to also be provided to address the issue
- Some females working in STEM-related fields develop the means to cope with any **social-identity threat**
- Using specific **inclusion criteria** during recruitment processes for STEM-related roles has been effective in increasing female participation
- **Female leadership potential** can also be improved using gender-based interventions within research institutions and with other STEM professionals
- **National policy and institutional structural processes** are also significant in supporting transformation in the gender-STEM field

3.4.1 Subject focused

A **subject-specific programme of intervention** at an American Medicine School (Women in Medicine and Health Science (WIMHS))[34] has been attributed with steadily increasing the number and percentage of female 'faculty and department chairs', along with good retention, career satisfaction and the development of an 'inclusive and supportive culture for women' since 2000 (Bauman, Howell and Villablanca, 2014, p. 1462). Delivery of the gender equity programme - Athena SWAN[35] – has also been evaluated with focus on academic medicine at one American university. Implementing the principles resulted in the creation of 'social space to address gender equity'; highlighting existing 'problematic practices'. However, it was reported that females were taking on a disproportionate amount

[32] WiSER
[33] Women in Medicine and Health Science (WIMHS)
[34] Women in Medicine and Health Science (WIMHS)
[35] The Athena SWAN Charter established in 2005 to encourage and recognise commitment to advancing the careers of women in science, technology, engineering, maths and medicine (STEMM) employment in higher education and research

of the work needed, and some **wider institutional practices**, national policies and societal norms undermined the impact of the programme (Caffrey, 2016, p. 1).

Evaluating the effectiveness of interventions targeting **medicine** formed the focus for an academic review of 18 different programmes. This literature review concluded that 'mentoring, professional development and /or networking' were the most popular activities, with participants responsible for 'opting into' the programme. The study reported that the quality of studies reviewed was low, yet they reported improvements in at least one indicator (usually self-reported) (Laver et al., 2015). For example, one workshop (Science Diversity) delivered to 126 science instructors concluded that the intervention had improved participants' awareness of gender bias (Moss-Racusin et al., 2016).

A large-scale longitudinal study of female academic retention rates at American medical colleges over 20 years found that those who attended **career development programmes** were 'significantly less likely to leave academic medicine than their peers for up to eight years after their appointment (Chang et al., 2016, p. 687). Thus, demonstrating the potential of continuing professional development programmes to support retention.

The majority of the interventions discussed are directly linked to traditional STEM subjects (e.g. physics, medicine). Nevertheless, the social sciences are included within the remit of this review and one study explored gender bias in political science. A crowd sourced website and Twitter feed supported content to counter the bias that can lead to female under representation and it was reported that after a few weeks almost 1,000 female political scientists had submitted their profiles. (Bealieu et al., 2017, p. 779).

3.4.2 Mentoring

Mentoring is reported in the literature to have proved effective in supporting female perceptions and decision making. One case study of such a **mentoring programme** undertaken in Ireland (WiSER) sought to 'develop sustainable practices to ensure that women can compete in research in an equitable manner with male colleagues using their scientific expertise, knowledge and potential'. The first role out of the programme in 2008 involved 20 female mentees and 21 mentors and mid- and end of term evaluations reported tangible outcomes such as job promotions, successful research funding applications and collaboration, membership of committees and academic journal publications. (Geber and Roughneen, 2011, p. 59; p. 69). It was also concluded that **goal setting** in career advancement was a very important element of the process for the women and although participants reported that they may have achieved their outcomes anyway – they may not have done so as quickly, with 'clear and careful management' contributing to speedy outcomes (Geber and Roughneen, 2011, p. 71). It is important to note that a recently launched charter for gender equality is linked to this work.[36]

Another intervention intended to improve recruitment, retention and advancement of females at universities in the USA - ADVANCE (National Science Foundation, 2017), provided the focus for a closer examination of the effectiveness of peer networks. However,

[36] SAGE (Systemic Action for Gender Equality) Charter of Principles for Gender Equality is an EU Horizon 2020 funded project. SAGE devises and implements interventions to advance gender equality in seven universities, acknowledging that despite the gender balance in holders of PhD degrees and in research posts across Europe, men are more likely to reach top level positions in research and academia.

despite positive outcomes, it was concluded that such an initiative needs to be delivered alongside **other policy and structural changes** supporting gender equity reform to be effective (O'Meara and Stromquist, 2015, p. 338; DeJonghe, Hacker and Nemiro, 2015, p. 393).

3.4.3 Addressing stereotypes

A few studies that focused on addressing gender stereotypes in the workplace were identified in the literature. Carnes et al. (2012) report that 220 staff at an American university participated in a 2.5 hour 'Bias Literacy Workshop', and that at least a third of these attendees committed to promoting gender equality following the session (Carnes et al., 2012, p. 77). This example supports findings noted in the above sections regarding the potential impact of short interventions. A later project based on a similar '**gender bias habit changing workshop'** explored the views of participants immediately following the session, and (self-reported) changes in behaviour three months later. This later study adopted a pair-matched, single-blind, cluster randomised controlled approach and concluded that there had been significantly greater changes among the study participants who were involved in the workshop. Changes observed in workshop participants included improved self-efficacy to engage in behaviour that promoted gender-equality, and an increase in (self-reported) actions to promote gender equality three months later (Carnes et al., 2015, p. 221). A follow-up study built on this and delivered further evidence to support the positive impact of psychological interventions on gender equality and diversity (Devine, et al., 2017, p. 211).

Another 'multifaceted intervention' in a medical school reported similar positive findings, when compared to other institutions, over a period of six years (Valantine et al., 2014, p. 904). Other studies report similar outcomes for diversity training initiatives, for instance one engaged 234 STEM-staff at an American university in a random matched assignment involving diversity training and found that the training 'had a positive effect on men's personal implicit associations towards women in STEM' (Jackson, Hillard and Schneider, 2014, p. 419).

A further example provides more specific detail regarding the format of an intervention where filmmakers and researchers partnered to develop **Video Interventions** for Diversity in STEM (VIDS) 'relative to controls, VIDS successfully reduced gender bias and increased awareness of gender bias', with substantial immediate effects reported among both men and women in the general population and by STEM academic staff (Moss-Racusin et al., 2018a, p. 236). A series of research studies explore the application of these video interventions further (Pietri et al., 2019; 2018 and 2017). However, it is also proposed that alongside the intention to increase bias literacy interventions must also provide 'concrete tools and avoid implying that these problems are insurmountable' (Hennes, 2018, p. 788).

A similar American study used a video intervention to look at the differences in the social identity threat for those engaged in engineering and those working in more gender balanced fields (58 participants). It was found that those working in engineering 'were less reactive to the experience of social identity threat', with their sense of belonging not 'influenced by the numbers of women portrayed at the professional conference'. Those working in more gender balanced fields commented on 'a reduced sense of belonging' and less interest to attend a male dominated conference, with it proposed that female engineers have a ‘means of **coping with the social identity threat**’ (Richman, van Dellen and Wood, 2011, p. 504). This was not evident for the younger age groups.

A more recent research output based on an ‘immersion seminar’ at a single American university involving 125 participants examined the role of ‘systems of oppression’, which have been central to women and gender studies, but in this context used to change ‘academic STEM culture’, with the structure and ideology of institutions the key to progress.[37] The intensive full time two-week programme, which also included follow-up meetings involved ‘intellectual analyses of systems of power, with attention to gender and its intersections with other forms of difference’ (Shaw et al., 2019, p. 17). Evidence of impact of the intervention included formalising the inclusion of screening criteria to be inclusive; this resulted in the proportion of female academics working in the Engineering Faculty doubling over four years.

> *‘Participants learn to behave better as individuals, but, more importantly, they plan and implement concrete action plans to shift the dynamics of institutional power toward greater equity and justice for everyone.’*
> *(Shaw et al., 2019, p. 18)*

3.4.4 Other priorities

Leadership development has also been a focus for some gender equality in STEM initiatives in academic research contexts. For example, one American study examined a course delivered to 30 females, with data collected using weekly journals as well as pre- and post- intervention questionnaires. This research concluded that the provision of strategies to both recognise and mitigate any impact of gender stereotypes was effective for improving early stage female academics’ belief in their leadership ability (Isaac et al., 2012, p. 307). Another experiential leadership programme for women at an American university reported outcomes for three cohorts (2010-2013 for 134 participants) and noted the positive impact of the training to enhance diversity and the advancement of women (Levine et al., 2015, p. 782).

A similar intervention in Germany – a Women Professor Program – used a quasi-experimental approach with long-term data to conclude that ‘the proportion of women professors increased more than would have been expected in the absence of the program’ (Löther, 2019). The Leadership Lab, launched in the United States in 2014 continues the focus on **female leadership in the STEM profession**; it provided ‘feedback, coaching and practical strategies’ to support female progress and retention in STEM professions for 50 women and data collected post-programme found that job promotions, awareness of bias and personal transformation resulted (Van Oosten, Buse and Bilimoria, 2017, p. 4).

Although research and employment specifically in higher education institutions provides the main focus in the academic literature, there are examples of programmes supporting employment in the wider STEM sector. For example, a small six-month pilot for 15 women in Scotland – Women Returners Scotland – provided paid internships and found that there

[37] The Difference, Power, and Discrimination (DPD) Program works with faculty across all fields and disciplines at Oregon State University to develop inclusive curricula that address institutionalized systems of power, privilege, and inequity in the United States.

were ‘reported gains in confidence and valuable learning on practical issues related to returning to work’ (Equate Scotland, 2016, p. 4).

Examples of long-standing interventions have been referenced above and, similarly to interventions aimed at university students, the STEM agenda has been addressed by addressing other priorities such as leadership development.

This section has explored the range of gender equality in STEM interventions that have been delivered across all education phases to different ages. It is apparent that some approaches are more commonly used than others. For example, the use of mentoring is prevalent in each stage, yet within mentoring there are different elements to be considered, such as the length of time for the intervention, the number and type of interactions, online and /or in person. Similarly, interventions delivered via courses over varying time periods have also reported successful outcomes, and yet it is not clear whether one particular delivery pattern produces a stronger impact than others.

Concluding comments and a discussion of the issues raised by this review, and the implications for addressing gender equality in STEM are discussed in the next section.

4. Conclusion and implications for addressing gender equality in STEM

A range of STEM-focused interventions have been evaluated and presented in the literature reviewed in the early years and primary school education, secondary school education and Higher Education phases, as well as evidence relating to research careers and other employment in STEM sectors.

Examples have been drawn from Wales, the rest of the UK and further afield, examining research outputs published since 2009. US-based studies dominate the existing evidence and focus mainly on the secondary school and Higher Education phases. According to the activity evaluated, some clear outcomes and critical success factors are evident throughout and these are summarised below.

The review identified that some positive outcomes are reported in each of the education phases and for the differing types of interventions. A range of methodologies were used to evaluate the STEM activities, and it is proposed that the larger scale projects and those that included comparison groups provide a stronger indication of potential critical success factors. However, although some of the studies included are relatively small-scale, these provide additional supporting evidence for the findings of the larger, more robust studies.

4.1 Early years and primary school education

The most frequently evaluated STEM intervention for this age group focused on **coding and robotics**, with the positive experiences for learners contributing to improvements in motivation to engage in technological activities. Studies reported that children already held stereotypical views at a young age, and therefore delivering **inclusive activities** for both boys and girls was reported to be a preferred approach for interventions. The evidence suggested that inclusive activities could increase boys' interest too and avoid increasing gender stereotypes, which it was proposed segregated activities can potentially contribute to.

Activities which are **developmentally and age-appropriate** were considered critical for successful engagement. Delivering activities over a **reasonable time period**, such as five to ten weeks, was also proposed as effective, as this was considered to be sufficient for children to be exposed to many opportunities to engage in STEM activities.

Ensuring children's **preferred learning styles** are accommodated was also considered to be important when planning and delivering STEM interventions. Practical, interactive and project-based activities as well as the use of technology was emphasised by some evaluators as being effective.

Exposure to **gender stereotypes**, even for a short time period was reported to affect stereotype endorsements. Whereas engaging with **role models** enhanced children's knowledge and understanding of potential STEM study and careers.

Although the evidence targeting early years and primary school aged children has been discussed in this review, the amount of evidence is limited in comparison to the other education phases. Consequently, there is potential to examine activities for this age group further, particularly when the impact of the informative early years on children's attitudes and perceptions of STEM is considered. Placing an emphasis on this age group would reiterate the Welsh Government's priority of ensuring a flying start in life for children.

4.2 Secondary school education

Computing and robotics provided a popular route to motivate younger children and similar activities were also successful with secondary-age children. However, while the evidence for the early years suggested that inclusivity (i.e. including boys and girls together in activities) should be a priority, some of the evidence for secondary phase pupils suggested that authentic collaborative learning was evident when activities were delivered to girls only.

Authentic, inquiry-based learning was also considered to be more effective for girls. Some researchers focused on the influence of the physical classroom environment on girls' interest in STEM. Evidence suggests that the presence of stereotypes or non-stereotype information in the immediate classroom environment can affect female views of STEM subjects.

Findings from the literature suggest that the balance of male and females in **collaborative working groups** can influence the quality of work produced. However, the evidence is not clear as to whether single-sex groupings or mixed gender groups work better on STEM projects.

Interventions that develop an awareness of **gender stereotyping** for this age group proved effective. Learners' **life experiences and interests** were also reported to be important when determining the subject content and focus for interventions, with one study concluding that a range of activities is needed to provide opportunities for individuals to engage – including those delivered outside normal school hours. Some of these interventions included successful residential opportunities, with the emphasis being on **interactive and project-based activities** that do not 'feel like school'.

Interventions of varying length and frequency of delivery (e.g. day workshops, after school clubs, one week intensive/ residentials, three months, year-long or three years) all reported positive outcomes for STEM career aspirations. It is evident that the resources and time available determine the length of an intervention.

Mentoring females – one-to-one, online or in groups – can all help female students clarify their career aspirations. Group mentoring was found to be particularly effective for developing networks and increasing STEM aspirations for some young people. The support of undergraduate and postgraduate students to deliver such mentoring opportunities is evident in the literature. The evidence shows that mentees need to be trained and that the inclusion of female mentors is also important. However, the evidence is less clear on which year group(s) would benefit most from these types of interventions.

Engagement with **role models**, over varying time lengths, can also influence females' views of STEM and stereotypes, yet short site visits and longer engagements with role models can result in varying impact. Nevertheless, authentic and immersive experiences were considered to be critical to success.

Ethnicity, and /or socio-economic background provided the focus for some STEM-based interventions, and some findings suggested that financial costs, a lack of social support and fear of failure can be perceived as barriers to further study for participants. The evidence indicates there is the potential to explore the intersectionality of gender in STEM further and consider other barriers that are reported to exist for particular groups of females studying or working in STEM.

Other factors can influence motivation as well as the direct interventions and activities discussed above. The role of **parents** in a child's decision making also needs to be considered and targeting parents with information about STEM study and careers has proved effective in increasing uptake in STEM subjects.

4.3 Post 16 and Higher Education

At Post 16 and Higher Education (HE), research conducted with undergraduate students was most frequently identified in terms of gender equality in STEM interventions. The evidence shows that some of the interventions delivered to other age groups are developed and delivered by those working or studying in HE.

Project-based, authentic subject-specific activities can positively impact female engagement in STEM and the pursuit of a STEM career. Using the media and implicit affirmation training can also contribute to females developing **'a sense of belonging'** in the field of STEM and help improve attitude and performance. The support of a **female mentor** was also reported to improve retention rates of women in STEM subjects. Some of the reported impacts of such mentoring programmes included increased networking activity, stronger scientific identity and interest in a STEM career. Delivering the mentoring opportunity virtually has also proved successful.

Using an **online/ virtual learning** environment to deliver STEM subject content has been reported to encourage more female participation and **increase the diversity of** course participants. The physical classroom environment also provided the focus for some evaluations – with a decrease in stereotype presentation resulting in greater female STEM identification. **Peer-led initiatives and tutoring** were reported to be effective for female retention rates and achievement. As with secondary school aged learners **small group working** was a focus for some interventions, with a positive impact on student engagement reported.

Exposure to **role models** as a tool to influence female views of STEM was reported to have an impact on this age group. Interventions that involved engagement with a female role model for a short period of time were reported to produce positive outcomes. Similar interventions which took place over a short period of time, such as 'personalised emails' also proved to be effective for female engagement. Whereas, others involving longer visits to engage with science professionals also reported positive attitudes towards STEM. Thus, as with other educational phases, although the **time allocated** to an intervention can vary there is still the potential for positive impact.

Activities that involved teams being composed of **multiple female members** (as opposed to dividing the female members between each team) were reported to lead to improvement in performance, with improvement in performance for males also reported by some. However, other studies examined the potential of delivering a **female-only STEM**

programme to improve women's sense of belonging and consequent engagement with STEM. These studies also reported successful outcomes.

Research examining **gender, STEM, ethnicity and socio-economic** background among undergraduates has also been undertaken and reported positive outcomes for participants' 'sense of belonging' and the development of strategies to cope with stereotypical views.

It is apparent that **multiple factors** influence female engagement with STEM subjects and STEM-related careers. Some interventions focused on **female confidence** and reducing test anxiety, which resulted in a positive impact on participants' achievement in STEM subjects and their sense of belonging.

4.4 STEM researchers and STEM-related employment

Although some interventions targeted females employed in STEM sectors or occupations, the majority focused on those employed in academic institutions.

Established **mentoring programmes** that successfully focus on either STEM or individual STEM subjects have been delivered and evaluated over several years. There are reports of such programmes successfully increasing the number and proportion of females at some academic institutions. It is reported that opportunities for networking and professional development within the mentoring experience had attracted participants to some programmes. Successful retention was also found to result from engagement in **career development programmes** for some female academics.

Supporting female perceptions and decision-making have also been reported to be positive impacts of mentoring programmes. In one study, **goal setting** in career advancement was identified as a very important element of the process, and it was considered that success was possibly achieved sooner than it would have been without such an intervention. Nevertheless, other studies have reported that even though such interventions have been successful, they need to be delivered alongside **other policy and structural changes** that support gender equity reform to be effective.

Positive impacts resulting from short workshop-style interventions **addressing gender stereotypes** are reported. This supports findings noted in the above sections regarding the impact of interventions that do not require a lot of time. Video interventions have also been used to influence views, and the evidence suggests that they too can have a positive impact. However, the literature also shows the importance of disseminating **effective tools** alongside these types of short interventions. For example, evidence suggests that the application of inclusion criteria for recruitment can play a role in developing the structure and ideology of institutions, and to drive the gender equality in STEM agenda further. It has also been found that females working in male dominated fields have developed **coping mechanisms** to address the social identity threat. This was not evident for the younger age groups.

Leadership development has also been a focus for some gender equality in STEM initiatives, with positive outcomes reported in enhancing diversity and the advancement of females. These programmes included coaching opportunities and practical strategies which supported career progress and retention.

4.5 Final note and next steps

This section has summarised the range of gender equality in STEM interventions that have been delivered to different age groups. It is clear that successful outcomes of such interventions include:

- engagement in a range of STEM-based activities;
- increased confidence and motivation to pursue STEM study /careers;
- better subject knowledge and understanding;
- improvements in achievement in STEM;
- improved awareness of gender stereotypes and bias;
- successful career goal setting and progression;
- positive impact on course and job retention rates.

It is also apparent that some approaches are more commonly used than others and thus provide an indication of critical success factors for gender equality in STEM interventions. For example, the use of mentoring is prevalent in each stage, yet within mentoring there are different elements to be considered, such as the length of time for the intervention, the number and type of interactions, online and /or in person. Similarly, interventions delivered via courses over varying time periods have also reported successful outcomes, and yet it is not clear whether one particular delivery pattern produces a stronger impact than others.

Nevertheless, evidence supports the effectiveness of a range of different types of gender equality in STEM interventions. Although most of the evidence identified relates to interventions aimed at secondary school and Higher Education, there are some common themes to the intervention types and critical success factors across all phases. There does not appear to be one single outstanding successful approach to addressing gender equality in STEM. Yet, key lessons learnt have been provided for each of the education phases and the evidence suggests that the most common types of intervention to improve gender equality in STEM relate to the following areas:

- delivering specific subject-based activities interactively;
- adapting the physical (or virtual) learning environment;
- addressing gender stereotypes relating to STEM to create gender inclusive learning environments;
- accommodating different learning styles and interests in delivering activities;
- providing positive role models and mentors;
- targeting parents as key influencers;
- addressing other related policy and structural factors.

The overview of existing STEM enrichment activities delivered in Wales reflects some of the interventions examined in this literature review. This indicates that there is much impactful work in this field already being delivered across Wales. However, there is potential to embed such activities across young people’s life experiences even further, which not only includes within their compulsory schooling experience but also within local communities and youth organisations. Determining for which age group activities would be most impactful needs further consideration and could be critical to future uptake and retention in STEM – as interest in STEM is cultivated for younger children, yet achievement appears to be a driver for activities as they become older.

The literature review finds evidence of positive outcomes resulting from a range of early years, primary and secondary-age interventions. However, the evidence is not conclusive in terms of which types of interventions are likely to have the greatest effect at different stages, or the magnitude of effects that would be expected from different types of interventions. Further data is required to evaluate the effects of interventions aimed at different age and target groups in Wales, and to regularly monitor the attitudes and aspirations of young people, so that any changes can be observed over time. Future longitudinal research could therefore explore in more detail the effects of early years and primary phase interventions on attitudes and choices relating to STEM post-16 education and careers. At the same time, interventions during those later life stages need to provide sufficient STEM opportunities, pathways and support so that any changes in attitudes and aspirations can be capitalised upon, and lead to improved gender equality in the economy and society.

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