An Roinn Oideachais
Department of Education

Review of Literature to Identify a Set of Effective Interventions for Addressing Gender Balance in STEM in Early Years, Primary and Post-Primary Education Settings

November 2020

Department of Education

Stage I literature review: Critical barriers to girls' participation
Stage II literature review: Effective interventions

Merrilyn Goos
Veronica Ryan
Ciara Lane
Keelin Leahy
Gráinne Walshe
Tracey O'Connell
John O'Donoghue
Achmad Nizar

UNIVERSITY OF LIMERICK
OLLSCOIL LUIMNIGH

Contents

Executive Summary

In Ireland there are significant gender imbalances in STEM (science, technology, engineering, and mathematics) subject choices made by male and female students at the post-primary level. Data on STEM subject enrolments indicate that the take up of the physical sciences and technology subjects is lower amongst girls, and the availability of these subjects is also more limited in all-female schools. It is critical to encourage greater participation of girls in these subject areas in order to address national skills needs and respond to the actions required in the *STEM Education Policy Statement 2017-2026* (Department of Education and Skills, 2017).

The aim of this systematic literature review is to identify effective interventions that address key barriers and build critical assets and skills that females need to learn, apply, and thrive in the STEM subject areas. The review was conducted in two stages. Stage I investigated barriers that females experience in participating in STEM subject areas and careers. Stage II identified effective interventions that address specific barriers, including measures of effectiveness of such interventions as well as evidence, where available, of their longer-term impact.

Ecological Framework for Investigating Gender (Im)Balance in STEM Education

There are many factors that can explain females' disadvantage in STEM. Moreover, these factors operate at multiple levels – individual, institutional, societal, and cultural – and they interact in complex ways. The review therefore used a multi-level analytical framework to identify and organise known barriers and interventions. This ***ecological framework*** identifies nested spheres of influence acting at the levels of Learner, Family, School, and Society, with numerous influences operating at each level (see Figure A). In this framework, early years learning is captured by the intersection of learner, family, and school, and the school level is taken to include all other types of organised educational settings.

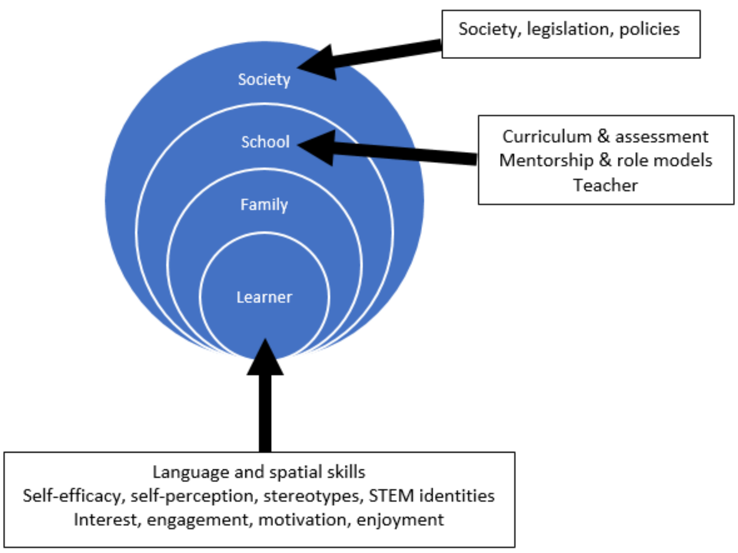

Figure A. Ecological framework

Stage I: Identifying Critical Barriers to Participation in STEM Education

The process of selecting studies in Stage I of the systematic literature review is summarised in Figure B.

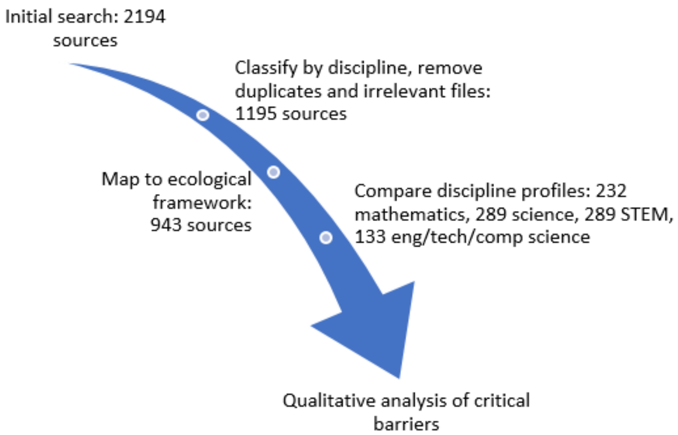

Figure B. Stage I literature search methodology

Stage I of the review involved manual and automated searches of electronic databases and grey literature (i.e., unpublished or non-commercial sources). This initial search yielded 2194 sources. Further manual inspection, resulting in removal of duplicates and irrelevant files, left 1195 sources that were then classified by discipline and mapped to the ecological framework. Additional automated and manual screening and removal of irrelevant files reduced the body of literature to 943 sources. Abstracts of these sources were then analysed to identify and classify critical barriers that females experience in participating in STEM education and careers. The results are shown in Table A.

Levels and Influences	Mathematics	Science	STEM	Engineering, Technology, Computer Science	Total
Learner					
Language and spatial skills	14	10	5	6	35
Self-efficacy, self-perception, stereotypes, STEM Identities	85	76	58	29	248
Interest, engagement, motivation, enjoyment	102	145	118	79	444
Family					
Family	75	54	60	30	219
School					
Curriculum & assessment	40	38	36	32	146
Mentorship & role models	15	23	48	20	106
Teacher	79	114	63	35	291
Society					
Society, legislation, policies	85	119	173	62	439

Table A
Final Mapping of 943 Abstracts by Discipline to Ecological Framework

The most important message emerging from Stage I of the literature review was that **there is no single barrier or level of influence that can be identified as the overriding factor in achieving gender equity in STEM education**. The Stage I analysis indicated a need to focus on intervention strategies for:

- **I.** ***Learners***: improving interest, engagement, motivation, enjoyment, and self-perceptions of learners of all ages, while addressing negative stereotypes and building productive STEM identities.

These strategies need to be developed and delivered at three intersecting levels, from early childhood to primary and post-primary education, rather than as isolated interventions:

- **II.** ***Family***: parent/guardian beliefs, attitudes, knowledge, encouragement;
- **III.** ***School and early years education***: teacher and early years practitioner beliefs, enthusiasm, knowledge, encouragement via appropriate interactions with learners; gender-inclusive curriculum and learning environment;

IV. ***Society***: communication of gender-inclusive social and cultural norms; promotion of approachable role models for girls and boys from various cultural and marginalised groups.

Stage II: Identifying Effective Interventions in STEM Education

The process of identifying effective interventions in Stage II of the review is summarised in Figure C.

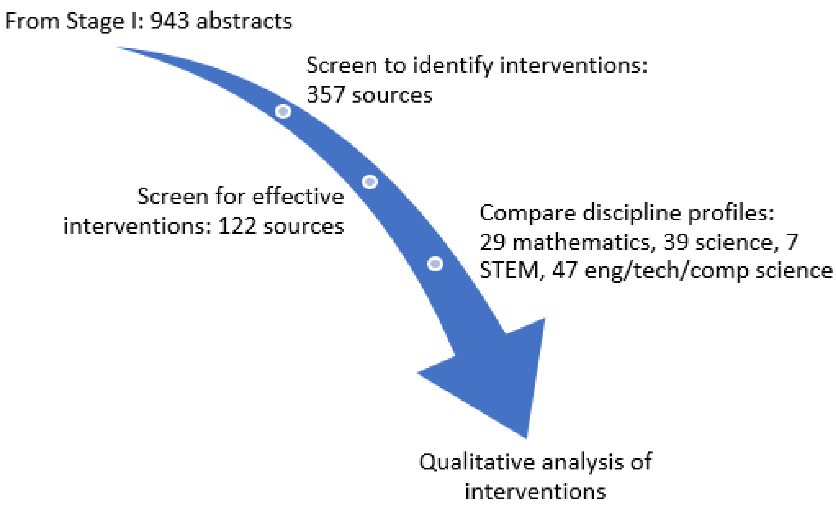

Figure C. Stage II literature search methodology

The literature sourced in Stage I was manually screened, first to identify intervention studies and then to select those that were judged to be effective. The criteria for effectiveness prioritised studies that had undergone expert peer review, provided a clear account of their methodology, supported claims of effectiveness with evidence, and used a sufficiently large sample size as an indicator of transferability. A small number of non-intervention studies was retained if they reported on surveys with very large sample sizes or on reviews of the literature on gender equity in STEM. This screening process yielded 122 studies, which were analysed to identify key features of interventions that were effective in addressing barriers to participation in STEM education and careers experienced by females. The results are shown in Table B.

Levels and Influences	Mathematics	Science	STEM	Engineering, Technology, Computer Science	Total
Learner					
Language and spatial skills	3	0	1	3	7
Self-efficacy, self-perception, stereotypes, STEM Identities	10	12	2	13	37
Interest, engagement, motivation, enjoyment	13	18	6	29	66
Family					
Family	10	11	0	13	34
School					
Curriculum & assessment	3	4	2	17	26
Mentorship & role models	7	6	2	6	21
Teacher	7	16	1	11	35
Society					
Society, legislation, policies	10	12	3	15	40

Table B
Final Mapping of 122 Interventions by Discipline to Modified Ecological Framework

A concise matrix was constructed to connect critical barriers at the levels of learner, family, school, and society with corresponding effective interventions. The categories of intervention represented in this matrix were:

1) Provide career counselling and information to students, teachers, and parents;
2) Provide mentoring and role models;
3) Encourage and support parental engagement with children or schools;
4) Attend to teacher/student interaction and language;
5) Provide relevant / innovative / inquiry-based / developmental curriculum;
6) Use mastery-oriented assessment;
7) Develop positive school culture;
8) Offer out-of-school programmes (e.g., summer camps, coding clubs);
9) Build science capital;
10) Challenge dominant representations of science.

Similarly to Stage I, an important message from the second stage of the literature review was **that there is no single type of intervention that can be identified as the preferred approach to achieving gender equity in STEM education**. Instead, it is important to recognise the interconnected nature of factors influencing young people's participation in STEM, and the need to reconsider how families, schools, and societal institutions in the STEM ecosystem think and act in relation to STEM education and careers. The key messages about effective interventions arising from the literature review can be summarised as the series of ***shifts in emphasis*** shown in Table C.

Shift away from ...	Shift towards ...
STEM education interventions mainly aimed at post-primary school students	Inclusive STEM education programmes that start in early childhood and continue through adolescence into adulthood, in both formal and informal educational settings
One-off or short-term interventions that lack connections to a broader purpose or programme	Long term, coordinated, multi-agency partnerships between families, schools, higher education, government departments, learned societies, business and industry, community organisations
Seeking to change girls' attitudes, beliefs, and behaviours	Seeking to change STEM education structures, practices, and the representation of STEM in wider society, that create barriers to gender-balanced participation

Table C
Proposed Shifts in Emphasis to Achieve Gender Balance in STEM Education

Towards Action

Based on the findings of this systematic review, we propose that a worthwhile purpose for the STEM education enterprise is to ***develop STEM capital through formal and informal education***, where STEM capital refers to young people's STEM-related knowledge, attitudes, experiences, and social contacts. To achieve this purpose, it will be necessary to ***develop, strengthen, and organise the entire STEM ecosystem***. Immediate decisions about prioritising a response might identify intervention points for maximum effect – in particular, during early childhood and early adolescence – while customising the response to the Irish context.

1. Background

Nationally and internationally, the need to advance science, technology, engineering and mathematics (STEM) education is recognised as being vital for meeting social and economic challenges and developing a scientifically, mathematically, and technologically literate citizenry. In many countries, however, there are gender differences in the participation and achievement of girls and women in STEM education and STEM careers, usually to the disadvantage of females.

In the international sphere, organisations such as UNESCO and the International Science Council (ISC) have produced reports or funded projects aimed at measuring and addressing these gender imbalances. For example, over a three-year period from 2017-2019, the ISC-funded Gender Gap in Science project (https://gender-gap-in-science.org/) surveyed more than 30,000 scientists around the world to document barriers and supports to academic and professional careers experienced by women and men, conducted a detailed investigation of gender patterns in millions of scientific publications, and developed a best-practice database of initiatives that address the gender gap in STEM education at all levels. Complementing this large-scale empirical approach is the UNESCO (2017) *Cracking the Code* report, which reviewed research literature and policy documents to identify factors influencing girls' and women's participation, progression and achievement in STEM education and interventions that help increase girls' and women's interest and engagement with STEM education.

Individual countries and regions have also been active in reviewing the status of girls and young women in STEM education and in proposing policy solutions. A variety of approaches is evident across countries in terms of the nature and strength of the evidence base informing such policy proposals. In the US, for example, the National Academies of Science, Engineering and Medicine (2020) analysed existing research on "policies, practices, programs and interventions for improving recruitment, retention, and advancement of women" (p. 1) in the fields of science, technology, engineering, mathematics and medicine. This report offers a set of actionable recommendations aimed at policy makers, higher education institutions and professional societies. In Australia, the Australian Council of Learned Academies commissioned a comparative study of educational policies and practices in relation to STEM around the world as the basis for framing a national STEM policy and strategy (Marginson, Tytler, Freeman, & Roberts, 2013). In addition to drawing on a range of international reports and policy documents, the Scottish Government's STEM education and training strategy was informed by a systematic process of consultation and discussion across a wide range of events, meetings and forums (The Scottish Government, 2017). The Nordic countries took a different approach to identifying gender-related challenges to STEM participation and strategies for addressing these challenges, by commissioning a comprehensive study based on multiple data sources: demographic data from national statistical offices, a literature review, surveys of students in five Nordic countries, focus groups and interviews with students across Nordic countries, and a mapping of existing gender equality initiatives in the Nordic countries (Puggarard & Bækgaard, 2016).

The STEM education landscape in Ireland is informed by the *STEM Education Policy Statement 2017-2026* released by the Department of Education and Skills (2017).

This statement communicates a vision for providing "the highest quality STEM education experience for learners that nurtures curiosity, inquiry, problem-solving, creativity, ethical behaviour, confidence and persistence, along with the excitement of collaborative innovation" (p. 12). The policy statement points to the intrinsic educational benefits of stimulating young people's curiosity and sense of wonder about the natural world, as well as the practical imperative of producing sufficient STEM graduates to drive Ireland's knowledge-based economy. The policy statement also argues that a high-quality STEM education is essential for all students, not only those aspiring to STEM-related careers, since modern democracies rely on STEM-literate citizens to make well-informed decisions about scientific issues of global significance affecting the nation's future. Within this context, there is an urgent need to investigate and address problems of low participation in STEM disciplines in Irish post-primary schools. The *STEM Education Policy Statement* acknowledges the importance of nurturing learner engagement and participation as the first of its four pillars of STEM policy development and action.

In Ireland there are striking gender imbalances in STEM subject choices made by boys and girls at the post-primary level. The trend is overwhelmingly for boys to select physical science and technology subjects, with girls outnumbering boys in biology. Females are also under-represented in higher education STEM courses. According to the Central Statistics Office (2018), the number of science, technology, engineering and mathematics (STEM) graduates in Ireland was 32.7 per 1,000 persons aged 20-29 in 2017, the highest rate in the EU28. Yet Ireland also had the highest gender differential in STEM graduates in the EU28, with 46.0 male graduates and 19.4 female graduates per 1,000 persons aged 20-29. It is likely that subject selection at post-primary level is one of several factors contributing to the under-representation of women in STEM-related tertiary study and careers.

2. Aims and Research Questions

The aim of this systematic literature review is to identify effective interventions that address key barriers and build critical assets and skills that girls need to learn, apply, and thrive in the STEM subject areas. Stage I of the review investigates critical barriers that females experience in participating in STEM subject areas and careers (research questions 1a and 1b). Stage II of the review identifies effective interventions that address specific barriers, including measures of effectiveness of such interventions as well as evidence, where available, of their longer-term impact (research question 2).

1. RQ1(a): What critical barriers do females experience in participating in STEM education and careers?
2. RQ1(b): Which of these barriers should be prioritised for further investigation in the Irish context?
3. RQ2: What interventions have proven effective in addressing the prioritised barriers?

3. Analytical Framework

A central claim made in all the policy documents and reports mentioned above, and supported by the substantial literature on gender differences in STEM participation and achievement, is that there are many factors that can explain females' disadvantage in STEM. Moreover, these factors operate at multiple levels – individual, institutional, societal, and cultural – and they interact in complex ways. Understanding and addressing the barriers that hinder female participation and achievement thus requires "holistic and integrated responses" (UNESCO, 2017, p. 12) rather than singular "solutions". As a consequence, the literature review needs to give attention to the interplay between personal, social, and institutional influences on the development of gendered academic aspirations by early childhood, primary and post-primary learners.

It is common to refer to a STEM *ecosystem* when considering the interplay of rich learning opportunities that can be provided in schools, in the home, in business and industry settings, and informal learning contexts such as museums, libraries, and other extracurricular or recreational programmes (Department of Education and Skills, 2017). This *ecological* approach not only acknowledges the multiple, overlapping influences on STEM participation and achievement, but also demands coordinated engagement of stakeholders across multiple contexts. We have therefore chosen a multi-level analytical framework that can identify and organise known barriers and interventions. The framework is based on Bronfenbrenner's (1989) Ecological Systems Theory, which proposes that there are nested spheres of influence acting on any individual and interacting with each other to create a complex web of effects that may differ from one person to another. We adapted UNESCO's (2017) version of this framework that appears in the *Cracking the Code* report, using the four levels of Learner, Family, School, and Society to organise the literature we sourced for this review.

4. Methodology

A systematic literature review seeks to collate evidence that fits pre-specified eligibility criteria in order to answer a specific research question. Systematic literature reviews typically have the following steps:

1. Define the research question(s).
2. Search for any recent reviews relevant to this question.
3. Develop a protocol for specifying inclusion/exclusion criteria and eligibility.
4. Build the search strategy.
5. Search the literature.
6. Select and critique studies.
7. Extract and synthesise data.
8. Analyse and present results.
9. Interpret results and draw conclusions.
10. Improve and update the review.

The procedures adopted for this review are described in the following sections.

4.1 Search Strategy

A rigorous systematic literature review required conducting searches of electronic databases, performing handsearches and examining grey literature[1]. All three searches employed strategic search terms. The title, author(s), source title, publication year, digital object identifier and web link for each document were recorded in an Excel spreadsheet. The search strategy sought to achieve a practical balance between sensitivity and precision.

4.1.1 Electronic Database Searches

The following electronic databases were searched: ProQuest, Web of Science, Scopus, EBSCO, Google Scholar, ProQuest Dissertations and Theses, and OpenGrey. The search criteria used a combination of search terms in abstracts, titles, topics and documents, for example:

(stem or stm or numerate disciplines or science or technology or math or engineering or physics or chemistry)

and

(early years education or school)

and

(girl or woman or women or gender)

[1] The term “grey literature” refers to research that is either unpublished or has been published in non-commercial form. Examples of grey literature include government reports, policy statements and issues papers, theses and dissertations, and research reports.

Search terms for the STEM disciplines did not explicitly include “biology” because the gender balance favours females in this area. However, including “science” in the search criteria ensured that the electronic database searches were sufficiently broad to capture relevant publications across the range of scientific disciplines. The search strategy deliberately combined “early years education or school” in order to identify publications that addressed STEM education across the target age range from early childhood to primary and post-primary education. Other criteria limited the search to publications from the last ten years (publication year > 2009) and in the English language. The precise search strategy for each electronic database is given in Appendix 1, together with the number of outputs yielded by each search.

4.1.2 Handsearches

To supplement the electronic database searches, handsearches were conducted by the research team to obtain files relevant to their discipline, namely Mathematics, Science, STEM and Engineering/Technology. This manual search of relevant journals was designed to capture articles that may have been missed in the database searches.

4.1.3 Grey Literature

To obtain grey literature and consequently improve the quality of the research findings, multiple search strategies were used: electronic databases, handsearches and Advanced Google Searches. The Open Grey and ProQuest Dissertations and Theses databases were searched using strategic search terms and a handsearch of these sources was also carried out. Google Advanced Search was used to find documents available in English, typically not available through the searches of the electronic databases. To ensure international coverage, England, Scotland, Wales, United States, Canada, Australia, New Zealand, Norway, Sweden, Denmark and Finland were specifically included in searches for reports relating to STEM and Gender. Important international sources (EU, UNESCO and OECD) were also included in the search. Government agencies, non-governmental agencies (NGOs), learned and professional societies (Ireland and UK), employers and employer organisations and a selection of international industries were included in this search. The precise search strategies are presented in Appendix 1.

An example of a single search strategy is:
(stem)

and

(gender)

and

(Central Statistics Office)

On Advanced Google 37 searches were executed with 10 results per search, yielding a total of 370 files. Of these 370 records, 163 records were found to be duplicates. The duplicates were removed yielding a total of 207 files.

The results from the electronic database searches, handsearches and grey literature searches were combined, yielding 2175 files. Open Grey database search results were then included, resulting in a total of 2194 files (

Search	**Initial Number of Files**
ProQuest	314
Web of Science	643
Scopus	58
EBSCO	398
Google Scholar	258
OpenGrey	19
Grey Literature (ProQuest Dissertations & Theses)	44
Handsearch_Journals	90
Handsearch_Grey Lit	370
Total	**2194**

Table 1). A search for duplicate titles was conducted and 389 files were removed.

Search	**Initial Number of Files**
ProQuest	314
Web of Science	643
Scopus	58
EBSCO	398
Google Scholar	258
OpenGrey	19
Grey Literature (ProQuest Dissertations & Theses)	44
Handsearch_Journals	90
Handsearch_Grey Lit	370
Total	**2194**

Table 1
Initial Search Results by Source: Electronic Databases, Handsearches and Grey Literature

4.2 Classification of Literature by Discipline and Removal of Irrelevant Files

Citation details of all publications yielded by the initial searches were either automatically downloaded into a spreadsheet as part of the database search process, or manually added to this master spreadsheet. They were subsequently classified according to the relevant STEM discipline that they addressed. This process combined automated classification, involving Excel macros, with the professional judgment of members of the research team. Several classification schemes were tested to distinguish between sources addressing STEM as a whole and STEM's constituent disciplines. This resulted in the master spreadsheet being re-organised into separate pages/worksheets for each of the STEM disciplines.

First, all Grey Literature sources collected through Advanced Google were classified as "STEM".

Second, for the electronic database and handsearch files, an automatised classification was set up as follows. If the title of the document contained "Math", it was removed from master list and sent to the Mathematics page of the spreadsheet. Then, the remaining documents were checked to see if they contained "Science" or "Physics" or "Chemistry" in their title (bearing in mind that these were the only science terms included in the search strategy). The documents that contained these words were sent to the Science page of the spreadsheet and removed from the master list. This process continued, checking titles for "Technology" and "Engineering" and "STEM" in this order. Some titles contained more than one of the terms "STEM" and one or more constituent disciplines. Classification of these titles was handled in the following ways. If any title contained both "STEM" and "Math", it was sent to the Mathematics page. Similarly, if any title contained "Science", "Technology" and "Engineering", this document was sent to the Science page.

All team members then were sent a copy of the search results, classified by discipline in separate pages/worksheets of an Excel spreadsheet file. Each team member was assigned to scrutinise the titles in the worksheet corresponding to their discipline expertise, and to mark for removal any titles considered to be irrelevant to the goals of the search. As a result of this manual screening process, a decision was made to create a separate classification for "Computer Science". Thus, all files in the Science page that contained "computer" were sent to a new page named "Computer Science".

4.3 Abstract Matching and Removal of Duplicates

To facilitate our analysis of the literature it was necessary to match abstracts to the titles of publications remaining in our master spreadsheet. This was done both automatically, using vlookups in Excel, and manually. There were only 51 publications for which no abstract was available from the original source, 34 of which were for publications in the STEM category. The process of matching abstracts to titles included publications sourced from handsearches as well as Open Grey searches.

In this stage of the review it became clear that further scrutiny of titles was needed to remove duplicates. Previously this had been achieved by looking for an exact title match. However, when working with abstracts it was apparent that some separate spreadsheet entries had the same abstract due to variations in the titles across different databases. For example, we discovered that the following three entries, originally listed as separate titles, were in fact the same because they had the same abstract:

- Seeking to improve African American girls' attitudes toward science
- Seeking to improve African American girls' attitudes toward science: A participatory action research project
- Improve African American girls' attitudes toward science a participatory action research project

These additional duplicate files were identified by manually searching for matching abstracts across the 1308 files in the master spreadsheet. Repetition of abstracts occurred across 237 files; duplicates were removed manually. This left 1195 publications, spanning the disciplines of mathematics, science, technology and engineering, STEM, and computer science. Table 2 shows the frequencies for each discipline.

Discipline	Frequency
Mathematics	274
Science	365
Technology & Engineering	120
STEM	394
Computer Science	42
Total	1195

Table 2
Final Search Results by Discipline: Electronic Databases, Handsearches and Grey Literature, with Irrelevant Titles and Duplicates Removed

4.4 Mapping the Literature to the Ecological Framework

This first stage of the literature review seeks to identify barriers to girls' and women's participation, achievement and progression in STEM education and careers. To organise the 1195 publications in our master spreadsheet into categories corresponding to critical barriers, we drew on the four-level ecological framework of the UNESCO (2017) *Cracking the Code* report (Figure 1). The framework compiles and organises factors at individual, family, institutional and societal levels, thus accounting for psychological, social, and cultural influences on females across the lifespan.

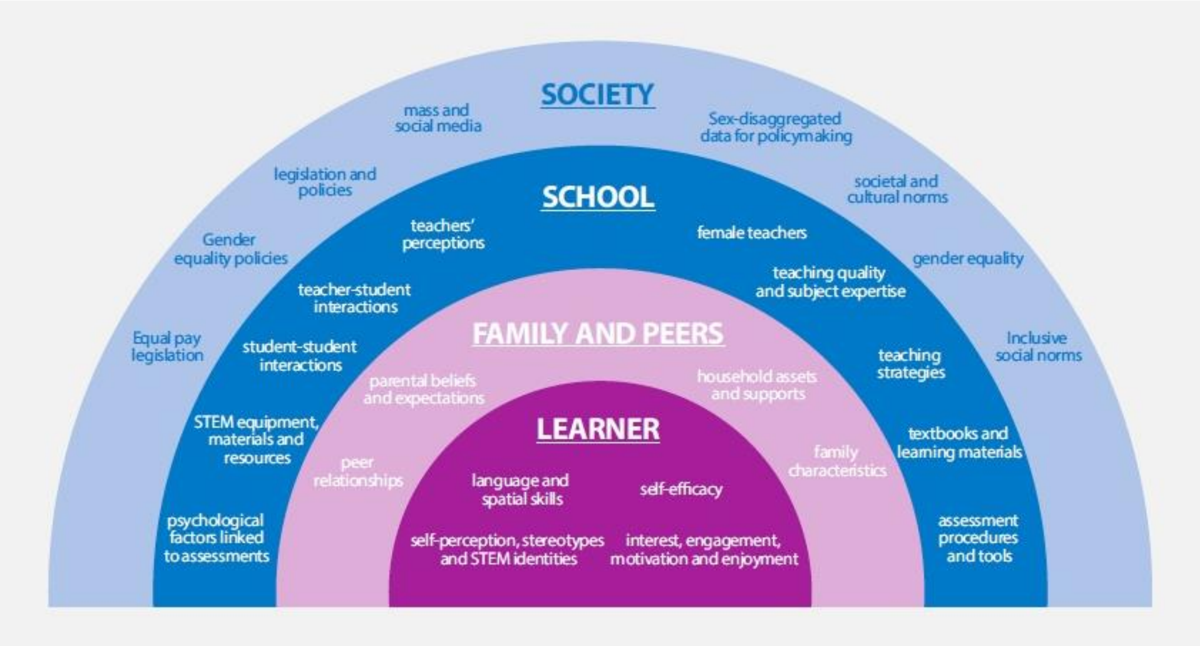

Figure 1. Ecological framework of factors influencing girls' and women's participation, achievement and progression in STEM studies (Source: Figure 36 in UNESCO, 2017)

We selected the following keywords, based on the levels and influences in the framework, to design an automated search of each of the 1195 abstracts:

V. Learner
VI. Language and spatial skills
VII. Role models
VIII. Self-efficacy
IX. Self-perception, stereotypes and STEM Identities
X. Interest, engagement, motivation and enjoyment
XI. Family
XII. Peers
XIII. School
XIV. Extra-curricular student engagement
XV. Curriculum
XVI. Mentorships and role models
XVII. Student-student interactions
XVIII. Teacher
XIX. Textbooks and learning materials
XX. Assessment
XXI. Society
XXII. Legislation and policies

Where necessary these keywords were further expanded into related search terms. This means, for example, that an abstract for a publication that was classified as "family" included one or more of the search terms "family", "parent", "child", or "household". Similarly, the keyword "teacher" was expanded to include the search terms "teaching strategies", "teacher recruitment", "teacher training", and "classroom management". Search terms were selected so as to be relevant to international literature rather than local usage, in order to capture the greatest possible range of publications. Thus the term "learner" includes early years learners, "teacher" includes early years practitioners, and "school" includes early years settings.

The categorisation of abstracts by keywords is summarised in Table 3. Note that the frequencies sum to more than 1195 and the percentages to more than 100% because most publications addressed more than one of the factors captured by these keywords.

Level in Framework	Keyword	Frequency	Percentage
Learner	Learner	769	64.35%
	Language and Spatial Skills	35	2.93%
	Role models	72	6.03%
	Self-efficacy	138	11.55%
	Self-perception, stereotypes and STEM Identities	137	11.46%
	Interest, engagement, motivation and enjoyment	444	37.15%
Family and Peers	Family	219	18.33%
	Peers	81	6.78%

Table 3
Initial Mapping of 1195 Abstracts to the Ecological Framework

Table 3

Level in Framework	Keyword	Frequency	Percentage
School	School	738	61.76%
	Extra-curricular student engagement	1	0.08%
	Curriculum	78	6.53%
	Mentorships and role models	106	8.87%
	Student-student interactions	0	0.00%
	Teacher	291	24.35%
	Textbooks and learning materials	9	0.75%
	Assessment	80	6.69%
Society	Society	376	31.46%
	Legislation and policies	124	10.38%

(cont.)
Initial Mapping of 1195 Abstracts to the Ecological Framework

Based on the distribution of frequencies resulting from the initial framework mapping of our literature sources, we generated a smaller set of categories to represent what seemed to be the most significant factors influencing females' participation, achievement and progression in STEM studies. We did this by selecting high-frequency categories and merging some lower-frequency categories. This process resulted in the following eight key categories that preserved the nested four-level ecological structure and subsequently guided our analysis and interpretation of trends in the literature:

XXIII. Language and spatial skills
XXIV. Self-efficacy, self-perception, stereotypes and STEM identities
XXV. Interest, engagement, motivation and enjoyment
XXVI. Family
XXVII. Curriculum and assessment
XXVIII. Mentorship and role models
XXIX. Teacher
XXX. Society, legislation and policies

All 1195 abstracts were once more subjected to an automated search against this new set of keywords. Only the 943 abstracts that matched at least one of these keywords were retained for the next stage of the analysis.

The final stage of the framework mapping involved a two-way analysis of the abstracts to categorise them according to discipline and categories of influence. At this stage a decision was made to combine the disciplines of computer science and engineering/technology. The discipline categorisation is displayed in Table 4 and the influence categorisation in Table 5. Note that in Table 5 the frequencies sum to more than 943 because most publications addressed more than one of the factors captured by the modified framework categories. We would also point out that this stage of the literature review did not explicitly distinguish between studies that investigate ***barriers*** and those that report on ***interventions***. Our findings are therefore presented mainly in terms of ***influences***.

Discipline	**Frequency**
Mathematics	232
Science	289
STEM	289
Engineering, Technology, Computer Science	133
Total	943

Table 4
Categorisation of Literature by Discipline after Framework Mapping

Levels and Influences	Mathematics	Science	STEM	Engineering, Technology, Computer Science	Total
Learner					
Language and spatial skills	14	10	5	6	35
Self-efficacy, self-perception, stereotypes, STEM Identities	85	76	58	29	248
Interest, engagement, motivation, enjoyment	102	145	118	79	444
Family					
Family	75	54	60	30	219
School					
Curriculum & assessment	40	38	36	32	146
Mentorship & role models	15	23	48	20	106
Teacher	79	114	63	35	291
Society					
Society, legislation, policies	85	119	173	62	439

Table 5
Final Mapping of 943 Abstracts by Discipline to Modified Ecological Framework

5. Identification, Interpretation, and Prioritisation of Critical STEM Barriers

The first research question addressed by this literature review asks: *What critical barriers do females experience in participating in STEM education and careers?* We used both automated and manual strategies to search, screen, organise, and classify a large body of literature relevant to this question. The results have validated the ecological framework used in the UNESCO (2017) *Cracking the Code* report, demonstrating not only the importance of influences at the levels of learner, family, school, and society, but also the overlapping nature of these influences. For example, from Tables 4 and 5 we see that the 232 publications in the mathematics discipline category referred to 495 instances of specific influences on participation, achievement and progression across the four levels of influence.

5.1 Quantitative Insights into Critical Barriers

Further insights into STEM barriers can be gained by analysing the profiles of influence within each of the disciplines represented in Table 5. Profiles are presented in Figures 2, 3, 4, and 5. In each case, the categories of influence are ordered from bottom to top in the sequence Learner (language and spatial skills, LSS; self-efficacy, self-perception, stereotypes and STEM identities, SSSI; interest, engagement, motivation and enjoyment, IEME), Family (F), School (curriculum and assessment, C&A; mentorship and role models, M&RM; teacher, T), and Society (society, legislation and policy, SLP).

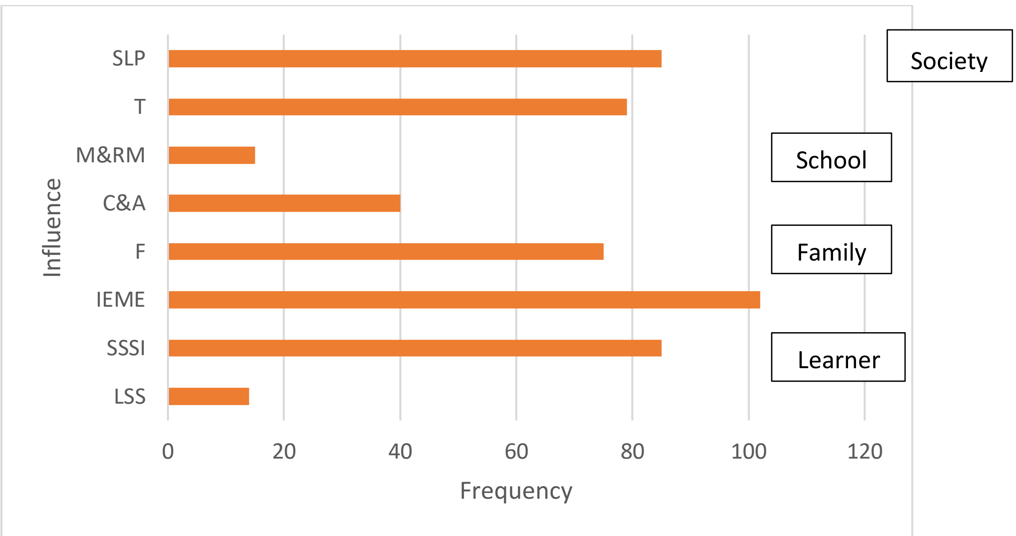

Figure 2. Profile of influences: Mathematics

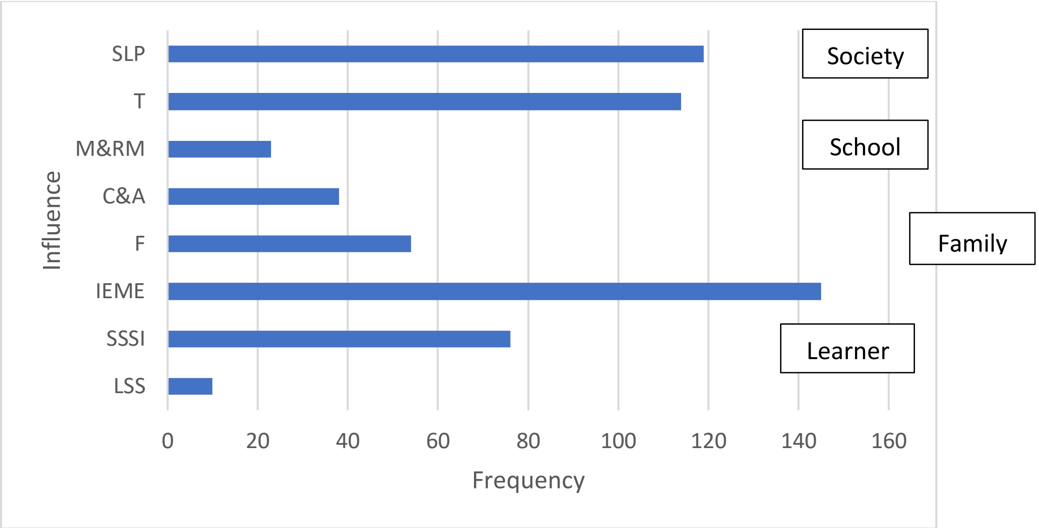

Figure 3. Profile of influences: Science

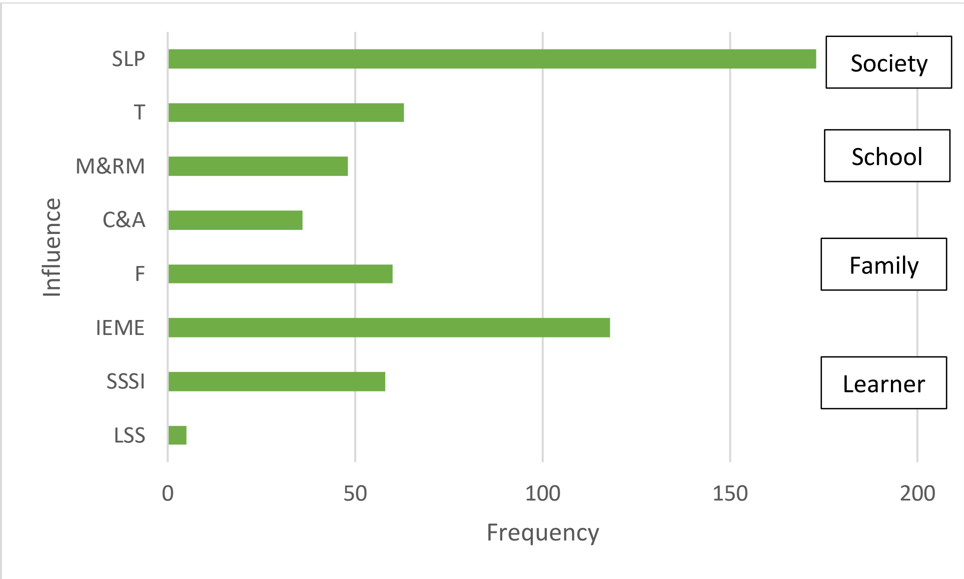

Figure 4. Profile of influences: STEM

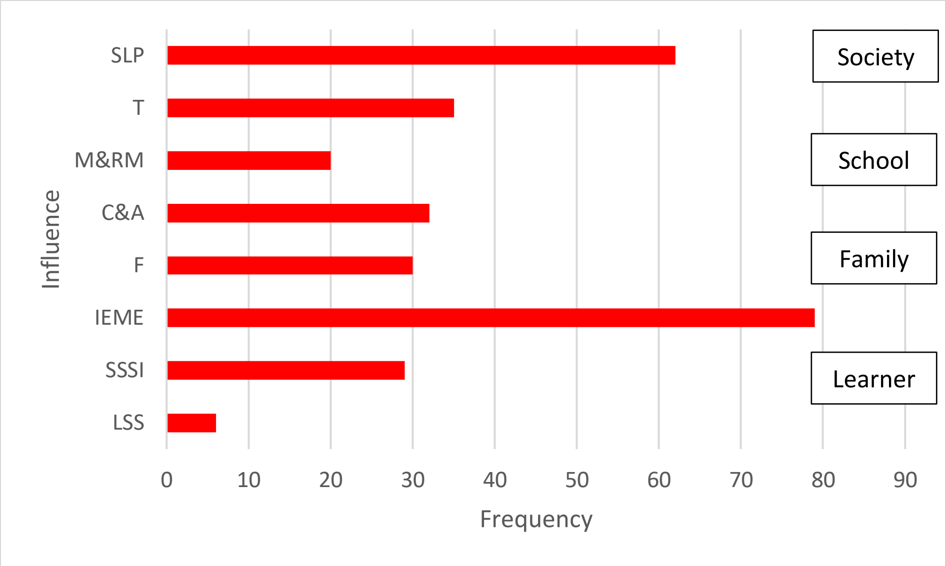

Figure 5. Profile of influences: Engineering, Technology, and Computer Science

There are many similarities, and some differences, between the discipline profiles. Across all four discipline areas the most significant influences – at least in terms of the quantitative emphasis that we identified from analysis of publications in this review – were in the areas of ***learner*** interest, engagement, motivation and enjoyment and ***societal*** issues. Mention of societal factors was especially prominent in the STEM discipline area (see Figure 4), and in all the discipline areas this may be a consequence of the increasing interest in development of STEM education policies in many countries rather than any research interest in societal factors influencing girls' engagement with STEM.

At the ***school*** level, the disciplines of mathematics (Figure 2) and science (Figure 3) displayed a similar profile, with strong emphasis on the influence of teachers and less on curriculum and assessment, mentorship and role models. While teachers were also the most important school-level influence in the disciplines of engineering, technology and computer science, this was almost matched by the emphasis placed on curriculum and assessment in these areas. In the general area of STEM (Figure 4), school-level influences were less significant overall, perhaps because of the lack of an agreed definition of how STEM is represented and operationalised in the school curriculum.

The influence of ***family***-level factors was somewhat moderate across science; STEM; and engineering, technology and computer science; but much stronger in mathematics. Along with teachers and peers in the school context, families can have a major influence on their children's self-efficacy, self-perceptions of ability, interest and motivation towards studies in STEM.

5.2 Qualitative Insights into Critical Barriers

Each member of the research team reviewed the set of abstracts corresponding to their main area of discipline expertise and prepared a short commentary on observable research trends and emphases concerning barriers to females' participation, achievement, and progression in STEM, mathematics, science, and engineering/technology/computer science education. This process yielded qualitative insights based on professional expertise to complement the automated, quantitative analysis presented in the previous section.

5.2.1 STEM Education

Despite interest in some countries in promoting an interdisciplinary approach to STEM education (e.g., Committee on STEM Education of the National Science and Technology Council, 2018), the literature extracted in our review process generally presents STEM as an umbrella term for its constituent disciplines rather than a new, integrated discipline. The research on both barriers and interventions shows a strong focus on engaging middle school girls in meaningful learning experiences; only two publications reported on early childhood issues in STEM education. The emphasis on societal issues documented in our quantitative mapping was mostly in reference to the importance of STEM to society and implications for policy makers, rather than an inquiry into barriers or interventions. There was surprisingly little evidence of research into the influence of teachers on students' experience and performance in STEM.

5.2.2 Mathematics Education

Based on our quantitative mapping of the literature, the most prominent influences on females' participation and performance in mathematics were at the ***learner*** level of the ecological framework: specifically, *interest, engagement, motivation and enjoyment* and *self-efficacy, self-perception, stereotypes and STEM identities*. Closer examination of the abstracts in this section of the literature revealed a general consensus that female students tend to have lower interest and enjoyment in mathematics than their male counterparts. Often these lower interest and enjoyment levels are linked to the consistently lower mathematics self-efficacy reported by girls compared to boys, in spite of negligible differences between the genders in overall mathematics achievement. Furthermore, self-efficacy emerges as a predictor for girls' interest in mathematics and their future occupational interest. The influence of self-efficacy would appear to outweigh the impact of gender stereotypes in the literature, although the latter remains an influential barrier to females' participation in and continuation with mathematics and STEM. Although anxiety is not specifically mentioned in the OECD (2017) ecological framework (Figure 1) or in our final modified version of the framework (Table 5), mathematics anxiety remains a consistent thread in the literature on gender differences in mathematics, with negative impact on females' STEM career interest. Girls' high levels of mathematics anxiety is closely related to their low self-efficacy levels, with mathematics anxiety often increasing with school decile and mathematics test anxiety, in particular, playing a key role. With regards to motivational differences between males and females, the expectancy-value theoretical model of achievement choices of Eccles et al. (1983) has been employed in several studies with findings indicating that females with fixed-traits beliefs are more likely to fall prey to the gender gap in mathematics, whilst developing a growth mindset might lead to higher mathematics achievement for female students compared to male students. Lower task value and less personally relevant instruction also emerged as significant factors in females' lack of engagement with mathematics.

Bronfenbrenner's ecological model of human development was employed in multiple studies in order to identify predictors for girls' interest and confidence in mathematics. Teacher influence was found to be a statistically significant predictor, as was extracurricular STEM involvement. Indeed, the important role of the *teacher* is reflected in the frequency of this influence in the ***school*** category (see Figure 2). Teacher support and general school support have been identified as more important to girls' engagement with mathematics than boys' engagement. A direct connection was found to exist between the teacher's own interests and excitement in making the STEM curriculum more meaningful for girls. Moreover, female elementary teachers' mathematics anxiety has been found to relate to girls' mathematics achievement via girls' beliefs about who is good at mathematics. The literature also suggests that positive feedback from their teacher (particularly male teachers) can be a factor in girls' identification with mathematics. This ties in with the importance of recognition in mathematics being more significant for females than males when choosing STEM courses or careers. This recognition in mathematics may be constrained by teachers' perceptions of boys and girls, which has been found to correlate with gender differences in mathematics at kindergarten and elementary level. Furthermore, there is consistent evidence in the literature that teachers at all educational levels often hold attributional bias in mathematics, attributing boys' success in mathematics to ability and girls' success to effort, while boys' failure in mathematics is more likely to be attributed to lack of effort and girls' failure attributed to their ability. While some studies propose that single-sex classrooms may mitigate mathematics gender stereotypes for students and teachers, other studies have found no gender differences in mathematics achievement and engagement between mixed and single-sex classrooms.

Outside of the classroom, there has been an increase in research on the relationship between ***family*** support and girls' achievement and engagement in mathematics, particularly with regards to mothers (see Figure 2). Some studies indicate that mothers' perceptions of their daughters' success in mathematics and the level of support girls receive from mothers can influence girls' achievement and engagement in mathematics. Moreover, mothers' mathematics gender stereotype may predict daughters' performance. In addition, parental mathematics anxiety can predict children's mathematics outcomes and endorsement of mathematics gender stereotypes is related to the level of mathematics anxiety. Research comparing high achieving students' continuation with mathematics study (post age 16) found that girls reported less support from family and social circles to continue studying mathematics. However, other research cautions that children's appraisal of their parents' evaluation of their abilities may stem from the child's own self-perception of their ability rather than the parents' actual evaluation.

Finally, on a broader ***societal*** level, socio-cultural background was found to be related to pupils' perceptions of male and female social roles and pupils' mathematics achievement in some studies. Multiple research studies advocate the need for more female role models in mathematics and STEM, including females from various ethnicities and cultures in order to challenge the perception of mathematics and STEM as a masculine environment and to encourage female participation and sense of belonging.

5.2.3 Science Education

Learner-level influences were significant within the science education literature. Many of the studies of students' *interest, engagement, motivation and enjoyment* focused on the separate subjects of physics, chemistry and biology, with their different patterns of gender (im)balance in participation. There is consistent evidence of female students' preference for biology, while male students preferred physics and chemistry. One large study (5000 participants) found that while there was no difference between boys' and girls' science interests during early childhood, the interest gap increased 20-fold by the end of high school and in a stereotypical manner with girls increasingly interested in biology and boys in physics. Other studies show that subject preferences are not necessarily related to achievement: girls frequently have achievement levels comparable with or even higher than boys, but still perceive some science subjects as being more "masculine" (e.g., chemistry, physics) than others (e.g., biology). It is argued that girls can feel like outsiders in chemistry and physics, irrespective of their achievement, and struggle to find a feminine identity as someone who is competent in science. Although interest in science in general may often be similar amongst girls and boys, girls tend to value the social aspect of learning in hands-on group activities and are more attracted to the societal relevance of science.

Also at the ***learner*** level, *self-efficacy, self-concept, stereotypes and STEM identities* figured strongly in the science education literature. Overall it is clear that female students' science self-efficacy is lower than that of male students, and in some studies this is shown to have an impact on STEM identities and future STEM career aspirations. There are some studies of elementary or pre-school children, showing how early perceptions of science self-efficacy impact future aspirations, but the majority of studies are of second-level education. Lower science self-efficacy and self-concept for females is shown to exist despite no gender-based achievement differences in some studies. In other studies, low achievement appears to cause lower self-efficacy. Nevertheless, it is clear from a variety of studies that gendered stereotypes of science are common and that female and male students perceive physical sciences as being aligned with male gender identity and life sciences more with female gender identity. There is evidence in the literature that exposure to negative stereotypes about women's intellectual abilities and stereotypes about scientists as "nerdy", eccentric loners may undermine gifted girls' confidence in their ability to succeed in science, their sense of belonging in these fields, and ultimately their interest in science. While positive role models have been found to reduce the prevalence of stereotypes associated with science careers, it is important that role models present an example that is seen by girls to be relatable and achievable.

School influences on participation and performance in science centre mainly on the *teacher* and there is an emphasis on building an inviting learning environment where both girls and boys feel encouraged, stimulated and challenged. Unfortunately, there is still evidence from many studies that girls in science class (and especially the physical sciences) experience different treatment by teachers, compared to boys, for example, in terms of the amount of talk, teacher expectations, and encouragement. In addition to the impact of instructional strategies, the science *curriculum* is implicated in contributing to gender imbalances in participation. Girls may see less personal relevance in physics problems concerned with artefacts and technological processes than in biology problems set in a societal or human context; however, some studies warn against adjusting science subjects to match what is perceived to be typical of boys' and girls' interests, since this can further reinforce stereotyped gendered identities. In general, there is support for building diverse, engaging, problem-based, socially relevant science contexts to increase interest and motivation in both male and female students.

While there is less evidence in the science education literature than the mathematics education literature of the role of the ***family***, parents' attitudes towards science and learning science at school have been found important in influencing adolescent self-concepts and importance values in all science subjects. ***Societal*** and cultural factors play a role here too, in communicating norms of what is "acceptable" for girls in terms of science careers. Students and families from marginalised and under-represented backgrounds may therefore need more support and mentorship to change gender-inflected views of possible STEM careers.

5.2.4 Engineering, Technology, and Computer Science Education

Quantitatively, there was much less literature in these combined fields than in any of the other discipline areas addressed by this review: only around 14% of the publications in our final listing were in the fields of engineering, technology, and computer science education. This disparity in research activity and emphasis, compared with that observed in mathematics, science, and STEM, may be a consequence of the different status of these fields in the school curriculum. In many countries, engineering appears as a discipline that can be studied only at the level of higher education or university, while the meaning of "Technology" in school settings is variable or ill-defined. Also, computer science education takes on different meanings and is delivered at different levels and in different contexts (ranging from informal out-of-school clubs to university degree programmes). The literature in these fields is thus less well-developed, with research into issues around gender balance still emerging.

A similar pattern of emphasis on ***learner***-level influences to that observed in the other STEM disciplines was evident in the literature on engineering, technology, and computer science. *Interest, engagement, motivation and enjoyment* appeared as important issues from early childhood, and female students' low confidence levels affects their motivation to continue into careers in these areas. Fear, social isolation, and lack of female role models also work to discourage girls from choosing to study these subjects. Lack of prior computing experience, prejudices and gender *stereotypes* concerning technology use, unenthusiastic teachers, and uninformed parents/guardians and administrators are cited as reasons for girls' lower participation and career aspirations. Clearly these factors interact with ***family*** and ***school*** level influences, illustrating the complex web of psychological, social, and institutional issues affecting females' participation. Some studies found that the influence of ***families*** plays a critical role in encouraging and exposing girls to technology and engineering, and put forward an argument in favour of outreach efforts to engage and inform parents/guardians. The educational level of mothers, the presence of engineers in families, and perceived family support emerged as important factors influencing whether a young person considered pursuing engineering studies. With regard to the ***school*** context, there was an almost equal emphasis on the role of *teachers* and the need to attend to *curriculum* design. Early childhood and primary school teachers are often fearful of technology, while at the post-primary school level there may be inadequate preparation and certification of specialist teachers. In addition, course designs seem to restrict teachers from presenting engineering, technology and computer science from a broad perspective that allows students to pursue problems of personal significance. For many female students, the learning environment in these fields is uninviting, uncomfortable, and often overtly “masculine”. All of these influences are reflective of ***societal*** values and attitudes about whether engineering, technology, and computer science are acceptable study areas and career destinations for females.

6. Key Messages from Stage I: Barriers

This first stage of the literature review identified 943 publications across mathematics, science, STEM, and engineering/technology/computer science education that referred to factors influencing girls' participation, achievement and progression in STEM studies. The quantitative and qualitative analyses of these literature sources validated the ecological framework used in the OECD's (2017) *Cracking the Code* report, and was consistent with the concept of a multi-level, interconnected STEM *ecosystem* proposed by Ireland's *STEM Education Policy Statement* (Department of Education and Skills, 2017). Despite some important differences in emphasis between the STEM fields that point to the need for a nuanced, discipline-specific response to gender imbalances in females' engagement and participation, the review has yielded some consistent messages on critical barriers.

The most important message emerging from the first stage of the literature review is that **there is no single barrier or level of influence that can be identified as the overriding factor in achieving gender equity in STEM education**. Much attention has been given to psychological factors affecting females' decisions about their studies and careers, but these apparent "choices" are greatly influenced by socialisation processes within the family, the school, and the wider society.

Insights from the review of critical STEM barriers indicate a need to focus on intervention strategies for:

XXXI. ***Learners***: improving interest, engagement, motivation, enjoyment, and self-perceptions of learners of all ages, while addressing negative stereotypes and building productive STEM identities.
These strategies need to be developed and delivered at three intersecting levels, from early childhood to primary and post-primary education, rather than as isolated interventions:

XXXII. ***Family***: parent/guardian beliefs, attitudes, knowledge, encouragement;

XXXIII. ***School and early years education***: teacher and early years practitioner beliefs, enthusiasm, knowledge, encouragement via appropriate interactions with learners; gender-inclusive curriculum and learning environment;

XXXIV. ***Society***: communication of gender-inclusive social and cultural norms; promotion of approachable role models for girls and boys from various cultural and marginalised groups.

Such an approach recognises that learning takes place in both formal and informal contexts. It also requires coordinated cross-sectoral support to align the efforts of authorities in the education, community, industry, and public engagement spheres.

7. Identification of Effective STEM Interventions

The aim of the second stage of the literature review is to identify effective interventions that address critical barriers experienced by females in participating in STEM education and careers (research question 2). Measures of effectiveness are to be identified, together with evidence, where available, of the longer term impact of the interventions.

7.1 Screening Abstracts to Identify Intervention Studies

Stage I of the literature review yielded 943 abstracts. In Stage II, members of the research team began by screening the abstracts corresponding to their main area of discipline expertise to identify those related to an intervention. In addition, 22 publications initially classified under STEM were re-assigned to engineering, technology and computer science; 2 interventions classified under STEM were reassigned to science; 7 studies relating to early childhood education provided by the Advisory Group were added to the spreadsheet (all classified under mathematics); and 13 publications were added to the science page. This screening process reduced the 943 files to 345.

7.2 Searching for Early Childhood Studies

Our Stage I search strategy (described in section 4.1) had specifically used search terms to target both early years education and school education. However, in light of current interest in early childhood STEM education, we decided to carry out an additional search of two electronic databases – Scopus and ERIC (ProQuest). The new search criteria used a combination of search terms in abstracts and titles, for example:

(stem or stm or numerate disciplines or science or technology or math or engineering or physics or chemistry)

and

(**kindergarten**)

and

(girl or woman or women or gender)

In all searches, the publication year of the document was > 2009 and the document language was English. The precise search strategy for each electronic database is given in Appendix 1.

After the abstracts were screened, 3 files were removed as they were deemed not relevant. The remaining 12 files were classified by discipline and added to the intervention spreadsheet: 10 were added to the mathematics page, 1 to the engineering, technology and computer science page, and 1 to the science page. This process brought the total number of intervention studies to 357. The discipline categorisation of the 357 interventions is displayed in Table 6.

Discipline	Frequency: All Abstracts	Frequency: Intervention Abstracts
Mathematics	232	57
Science	289	113
STEM	289	67
Engineering, Technology, Computer Science	133	120
Total	943	357

Table 6
Categorisation of Intervention Literature by Discipline after Screening of Abstracts

7.3 Screening for Effective Interventions

All intervention files were further classified using the following 9 categories to describe their essential features:

XXXV. Country/ geographical region
XXXVI. Research aims/questions
XXXVII. Theoretical perspective
XXXVIII. Number of participants
XXXIX. Duration
XL. Educational level (e.g., early childhood, primary, post-primary)
XLI. Type of participants (e.g., children, students, teachers, parents, other adults)
XLII. Type of intervention
XLIII. Evidence of effectiveness

The next stage of screening sought to identify interventions that had been proven to be effective. We developed broad criteria for screening the intervention studies, based on principles of research quality that value expert peer review, clear reporting of methodology, and claims of effectiveness that are supported by evidence. We also considered the scale of interventions to be important in this context, assigning more value to studies with larger sample sizes as a possible indication of transferability. Members of the research team thus scrutinised the publications within their own discipline areas and marked for removal any that did not satisfy the following four inclusion criteria:

XLIV. Published and preferably peer reviewed (i.e., theses were removed)
XLV. Sample size ≥ 20 participants
XLVI. Explicitly detailed methodology

XLVII. Describes how effectiveness was evaluated

In relation to the fourth inclusion criterion, we drew on the framework of Kirkpatrick and Kirkpatrick (2006) to distinguish between four levels of evaluation:

- Level 1 (Reaction): How satisfied were participants with their experience?
- Level 2 (Learning): How did participants' knowledge and skills improve, or attitudes change?
- Level 3 (Behaviour): How did participants apply their learning and how did this result in personal change in behaviour?
- Level 4 (Results): How did the programme impact on organisational or societal factors?

Generally, Level 1 evaluation does not provide the kind of information that is valued by policy makers and other stakeholders, and it is important also to show what happens as an outcome of an intervention (Levels 2 to 4) and not just within it.

There were two exceptions to these screening criteria. Non-intervention studies were retained if they reported on surveys with very large sample sizes or on reviews of the literature on gender equity in STEM (or mathematics, science, or engineering/technology/ computer science) education. As a result of this closer scrutiny of full publications (rather than abstracts, as in the earlier stages of the literature review), there was some further revision of discipline classification and reassignment of files.

After several iterations of screening for effectiveness and monitoring the application of our screening criteria, 122 interventions remained. The discipline categorisation of the interventions is displayed in Table 7 and the mapping of interventions to the modified ecological framework is displayed in Table 8. Note that in Table 8 the frequencies sum to more than 122 because most studies addressed more than one of the factors captured by the modified framework categories.

Discipline	**Frequency**
Mathematics	29
Science	39
STEM	7
Engineering, Technology, Computer Science	47
Total	122

Table 7

Categorisation of Intervention Literature by Discipline after Screening for Effectiveness

Table 8
Final

Levels and Influences	Mathematics	Science	STEM	Engineering, Technology, Computer Science	Total
Learner					
Language and spatial skills	3	0	1	3	7
Self-efficacy, self-perception, stereotypes, STEM Identities	10	12	2	13	37
Interest, engagement, motivation, enjoyment	13	18	6	29	66
Family					
Family	10	11	0	13	34
School					
Curriculum & assessment	3	4	2	17	26
Mentorship & role models	7	6	2	6	21
Teacher	7	16	1	11	35
Society					
Society, legislation, policies	10	12	3	15	40

Mapping of 122 Interventions by Discipline to Modified Ecological Framework

8. Analysis and Evaluation of Effective STEM Interventions

The second research question addressed by this literature review asks: *What interventions have proven effective in addressing the prioritised barriers (to participation in STEM education and careers)?* In Stage II, we used automated and manual strategies to screen, organise and classify the literature that we had identified in Stage I of the review, with the aim of identifying effective interventions. Once again we found that the ecological framework used in the UNESCO (2017) *Cracking the Code* report allowed us to highlight different levels of influence – the learner, family, school, and society – that may be targeted by interventions.

8.1 Quantitative Insights into Effective Interventions

Insights into effective STEM interventions can be gained by examining the profiles of interventions within each of the disciplines represented in Table 8. Profiles are presented in Figures 6, 7, 8, and 9. The focus of the interventions is represented via the levels of the ecological framework, ordered from bottom to top in the sequence Learner (language and spatial skills, LSS; self-efficacy, self-perception, stereotypes and STEM identities, SSSI; interest, engagement, motivation and enjoyment, IEME), Family (F), School (curriculum and assessment, C&A; mentorship and role models, M&RM; teacher, T), and Society (society, legislation and policy, SLP).

Across the discipline areas, the most frequent focus was on interventions that build ***learner*** interest, engagement, motivation and enjoyment. Interventions developing learners' language and spatial skills were the least frequent type, but more common in mathematics and the general area of STEM. However, the smaller sample size in the latter two disciplines means that this observation should be made cautiously. In mathematics, high-frequency gender interventions also targeted the ***family***, and when combined with the emphasis on increasing learner interest this suggests a common approach that works towards engaging families with their children's mathematics learning. In both mathematics and science, there was also significant emphasis on addressing ***learner*** self-efficacy, self-perceptions and stereotypes, an approach that most likely involves teachers and would therefore explain the high frequency of ***school***-level mathematics and science interventions targeting the teacher. In mathematics there was also substantial attention given to providing students with mentors and role models.

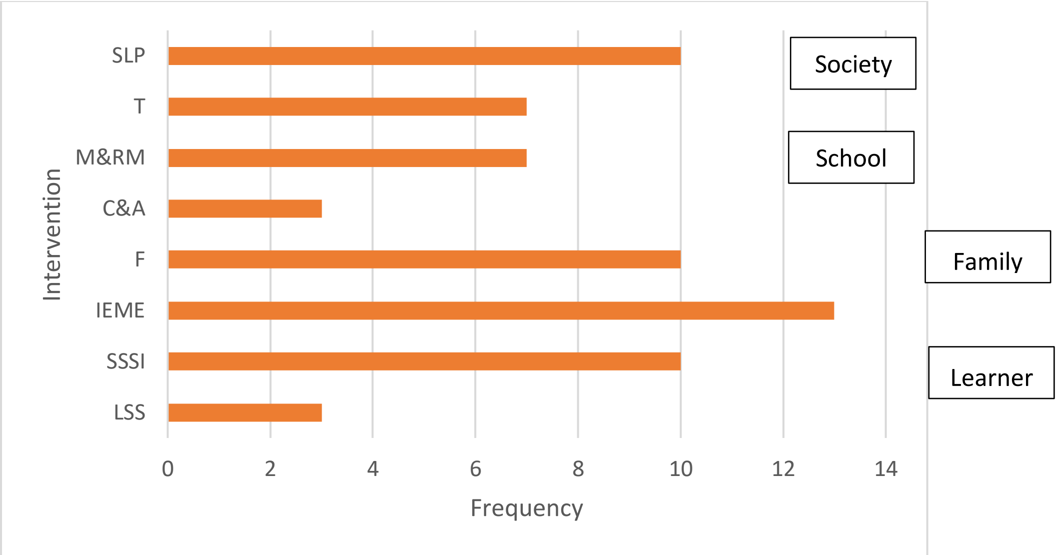

Figure 6. Profile of effective interventions: Mathematics

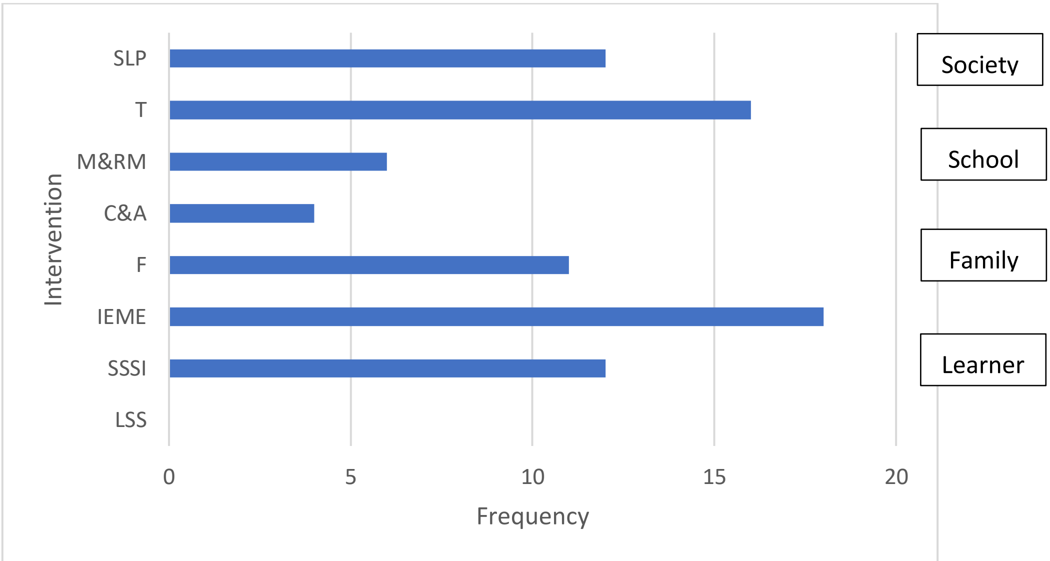

Figure 7. Profile of effective interventions: Science

In the disciplines of engineering, technology, and computer science, and in the general area of STEM, a somewhat different profile of interventions was apparent. By far the most frequent types of intervention were those that aimed at the ***learner*** level to develop student interest, engagement, motivation and enjoyment. ***Family***-oriented interventions were relatively common in engineering, technology, and computer science, but not observed at all in the STEM field. At the ***school*** level, teacher-oriented interventions were less common in the STEM field than in engineering, technology, and computer science. This observation may reflect the lack of a defined role for STEM teachers in schools or simply be a consequence of the very small sample size in STEM interventions. In engineering, technology, and computer science, interventions related to gender-responsive curriculum or assessment comprised the most common school-level initiatives.

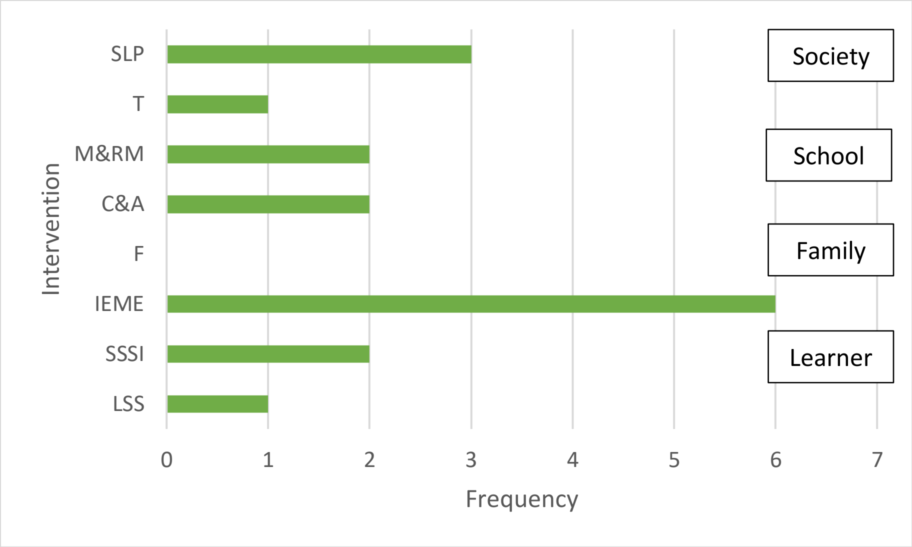

Figure 8. Profile of effective interventions: STEM

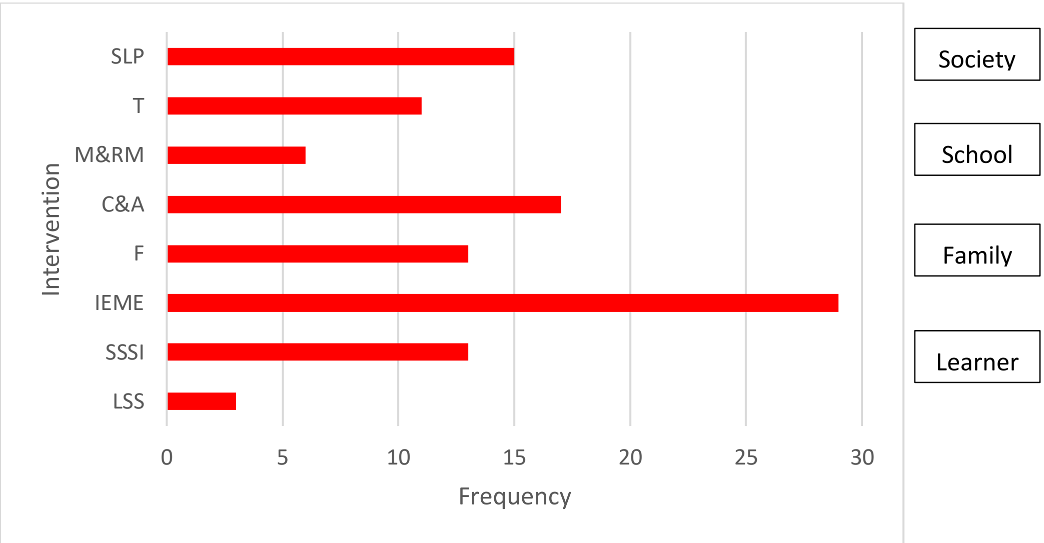

Figure 9. Profile of effective interventions: Engineering, Technology, and Computer Science

We also categorised effective intervention studies according to the types of participants and the educational level that was targeted. Figures 10 and 11 show the distributions by ***educational level*** and ***type of participants***, as well as the overlaps between these.

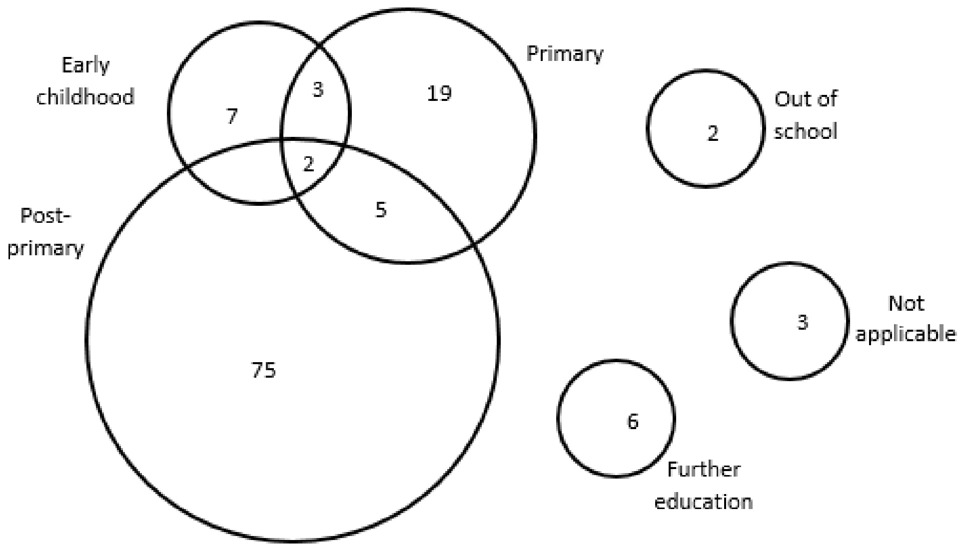

Figure 10. Distribution of effective interventions by educational level

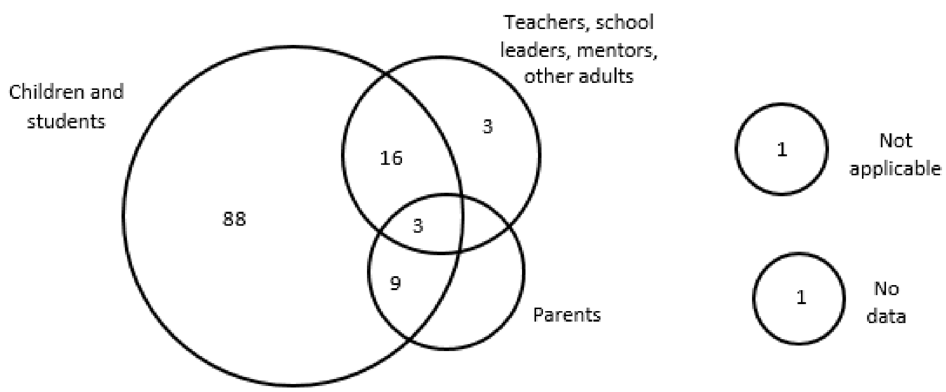

Figure 11. Distribution of effective interventions by type of participant

Consistent with the observed emphasis on interventions pitched at the ***learner*** level of the ecological framework, in around 72% of effective interventions the only participant group was *children* (i.e., in early childhood settings) *and students* (in schools). Two-thirds of effective interventions were conducted in *post-primary school* settings, with most of the remainder in early childhood settings and primary schools. Only 2 effective interventions took place in out-of-school contexts, a surprising result given the significant support for informal STEM learning activities evident in many countries. This may indicate that more attention needs to be given to evaluating out of school programmes and seeking publishable evidence of their impact. Nearly one-quarter of effective interventions involved children/students interacting with teachers, parents, mentors, or other adults. While there is value in addressing learner engagement at all educational levels, it appears that most of the effective interventions identified in this review attend to already existing gender imbalances in post-primary STEM participation. This observation suggests that more attention needs to be given to interventions involving young children and their parents to build strong foundations for learning at home as well as at school.

8.2 Qualitative Insights into Effective Interventions

Each member of the research team reviewed the set of publications within their own area of discipline expertise and prepared a commentary on research trends concerning effective interventions that improve females' participation, achievement, and progression in STEM, mathematics, science, and engineering/technology/computer science education. This process identified representative or exemplary studies, which are discussed in the following sections and included in the Matrix of Barriers and Effective Interventions (Appendix 2).

8.2.1 STEM Education Interventions

The review of scholarship in the STEM category after Stage I screening based on abstracts only produced 289 contributions worthy of further consideration within the terms of the project and its design. Further reading with a focus on identifying interventions led to the retention of 64 possible interventions, programmes and initiatives designed to address the gender gap in STEM. Of these actions, only a very small number (7) survived a close examination of relevant papers using the systematic review's framework for evidence-based scholarship/research. In turn, this number yielded 4/5 initiatives worthy of retention in the review.

An initial observation is that 4/5 interventions is an unexpectedly small return in this category and deserves some consideration in its own right. Immersion in the STEM literature over the period of the review points to some possible explanations for such a small number. While the gender gap and females' participation in science and engineering subjects has long been a matter of concern, STEM as an identifier is very recent in origin dating from the early 1990s, and only used by the US National Science Foundation since 2001. The evolution of STEM as an area of academic scholarship follows a recognisable path, from identifying barriers, to understanding issues, finding suitable theoretical frameworks culminating in academic rigour. Meanwhile, actions or interventions are implemented on an ad hoc basis to address perceived issues, and they in turn take time to attain rigorous standards, particularly in relation to evaluation standards. So, according to this analysis, it is premature in terms of the evolution of STEM as an area of scholarship to expect a large number of rigorous interventions. Consequently, many of the interventions failed the evidential standards set by the review. In addition, since STEM disaggregates into its constituent disciplines, and gender issues have long being a matter of concern and study in these disciplines, scholarship in these disciplines is likely to be well established. The review process supports this argument in terms of individual numbers of interventions identified in each discipline and in the re-assignment of abstracts and papers from the STEM category to individual disciplines. There is also a reluctance to let go of potentially interesting contributions early on in the process that fail under scrutiny to meet the project standards for scholarship later on.

Since such a small number of interventions (4/5) does not lend itself to analysis by patterns, we instead give a brief summary of each and end with some general comments on the set.

Intervention 1: Falco, L.D., & Summers, J. J (2019). Improving career decision self-efficacy and STEM self-efficacy in high school girls: Evaluation of an intervention. *Journal of Career Development*, *46*(1), 62-76.

Aim/purpose: The specific purpose of this study is to examine whether a small group intervention is effective at improving the career decision self-efficacy and STEM self-efficacy for adolescent girls. The intervention uses four sources of self-efficacy performance accomplishments: observational learning, managing anxiety, experiencing verbal persuasions, encouragement.

Effectiveness: Participants in the treatment group improved significantly on variables of career decision self-efficacy, and STEM self-efficacy and gains were increased in a 3-month follow-up as measured by appropriate instruments and statistical analyses.

Evidence: Using repeated measures analysis of covariance results indicated that there was a significant improvement in career decision self-efficacy and STEM self-efficacy, and gains increased at 3-month follow-up when participants in the control group (n=44) and in the treatment group were compared.

Scale: A treatment group of 44 girls from this sample participated in a 9-week intervention, and results were compared with a control group (no treatment) of 44 girls from the same sample.

Participants: The study involved 88 girls, Latino and White, 40 first-year and 48 second-year high school girls from the same high school in the US.

Intervention/study 2: Stoeger, H., Debatin, T., Heilemann, M., & Ziegler, A. (2019). Online mentoring for talented girls in STEM: The role of relationship quality and changes in learning environments in explaining mentoring success. *New Directions for Child and Adolescent Development*, *168*, 75-99.

Aim/research questions: This is an online mentoring intervention using CyberMentor, a Germany-wide online mentoring program. The research questions are reproduced below.

RQ 1: Is suitably implemented online mentoring (operationalised via relationship quality) related to an increase in STEM-specific educational capital in talented female students?

RQ 2: Is positive change in STEM-specific educational capital associated with an increase in STEM activities, elective intentions in STEM and certainty about career plans?

RQ 3: Is suitably implemented online mentoring (operationalised via relationship quality) indirectly related to an increase in STEM activities, elective intentions in STEM, and certainty about career plans via an increase in educational capital?

Effectiveness: Positive changes were found related to two mentoring outcomes. The findings suggest that this approach to online mentoring was indirectly related to an increase in two mentoring outcomes (1) learning environments of mentees, (2) elective intentions in STEM, through an increase in educational capital.

Evidence: Rigorous statistical analyses/longitudinal mediation analyses using the parallel process latent growth curve approach. Questionnaires filled out at 3 points in time, and standard measures used for attributes in study (e.g., educational capital).

Scale: 998 talented secondary school girls/M=13.82 years interested in STEM.

Participants: Mentees are students between the ages of 11 and 18. Each mentee is supervised by a personal mentor for at least 1 year and has at least 30 minutes contact per week.

Intervention 3: Ward R. B., Miller J. L. Sienkiewicz, F., & Antonucci, P. (2012). ITEAMS: Increasing the self-identification for girls and underserved youth in pursuing STEM careers. *Journal of Systemics, Cybernetics and Informatics*, *10(*1), 95-99.

Aims/research questions/Type: ITEAMS (Innovative Technology-Enabled Astronomy for Middle Schools) – an out-of-school program with online, robotic telescopes as its central focus.

The study was designed to investigate two research questions: (1) How effective is the project in enhancing student STEM understanding, and in creating and sustaining a link between STEM experiences and STEM careers for the participants? (2) To what degree do students perceive that the skills and conceptual knowledge developed in the project are potentially valuable for entering a STEM career or related vocation (p. 96)? This paper is concerned mainly with outcomes related to question 1.

Effectiveness: Researchers found statistically significant gains in subject matter knowledge regardless of gender, ethnicity or school, and found girls express less interest than boys in STEM careers from early grades (five and six). These are early findings and relate mainly to research question 1.

Evidence: The researchers used a quasi-experimental design involving online surveys and assessments, the former to determine subject knowledge and the latter attitudinal changes about career choices. Participating students took pre-, intermediate, and post- subject-matter tests and career-interest surveys. Findings are based on rigorous statistical analysis using 97 matched pairs of assessments and surveys, involving 47 girls and 50 boys.

Scale: 140 middle school students and underrepresented minority students. The intervention was out-of-school lasting 1 school year.

Participants: 140 girls and underrepresented minority students (5^{th}-8^{th} grades)/Middle school, US).

Intervention 4: LaForce, M., Noble, E., King, H., Century, J., Blackwell, C., Holt, S., ... & Loo, S. (2016). The eight essential elements of inclusive STEM high schools. *International Journal of STEM Education*, *3*(1), 21. https://doi.org/10.1186/s40594-016-0054-z

Aims/research questions: The nature of STEM schools is contestable and there is no consensus. This makes it difficult to evaluate their effectiveness and scale-up successful models.

In this study, the researchers address the questions:

RQ 1: What is it that inclusive STEM high schools actually set out to do?

RQ 2: What are the essential characteristics (or components) of these schools?

RQ 3: What outcomes are intended for various stakeholders, students, staff, and community?

Effectiveness: The study identified 76 critical components of STEM schools and derived a theoretical framework of eight elements that represent the common goals and strategies employed by inclusive STEM high schools across the US. The framework includes:

- Personalisation of learning;
- Problem-based learning;
- Rigorous learning;
- Career, technology, and life skills;
- School community and belonging;
- External community;
- Staff foundations;
- External factors (pp. 7-8).

This framework does not identify STEM subject content as a defining characteristic across school models.

Evidence: The researchers adopted a bottom-up approach to derive a theoretical model for inclusive STEM high schools by employing a “component approach” (Century et al., 2010; Hall & Hord, 1987; cited in LaForce et al., 2016).

Scale: 20 STEM schools in the US.

Participants: STEM schools, teachers, and principals.

Interesting findings/Conclusions: Findings suggest that STEM school identity is perceived by their principals and stakeholders as anchored in, and built on, constructivist-like pedagogy, transferrable skills, school culture, and rigorous instruction across all subjects in the curriculum, not just STEM subjects.

Action/Intervention 5: Johnson & Johnson WiSTEM^{2}D or Women in Science, Technology, Engineering, Mathematics, Manufacturing, and Design (STEM^{2}D).

While strictly speaking, this example does not meet the inclusion criteria it is hard to ignore such a large-scale industry initiative. Launched in 2015 and led by a network of volunteers from across Johnson & Johnson and its local operating companies, this ambitious initiative involves:

K–12 outreach: Sparking enchantment with STEM2D subjects in young women and girls through creative problem solving and play.

University talent: Inspiring career paths, by partnering with select academic institutions to develop high-impact strategies for recruiting, retaining, and engaging women leaders.
Professionals: Tapping into the power of diversity through reimagined recruitment and retention of the world's best technical female talent. (https://www.stem2d.org/s/STEM2D_RESOURCEGUIDE_COMPRESSED.pdf)
Aim: The goal is to engage females at all ages and throughout every cycle of their educational and professional lives in STEM^{2}D fields, as well as expand the field of focus by including manufacturing and design. It is assumed that, by cultivating girls' STEM^{2}D at an early age, they will be well positioned to pursue higher education and careers in the STEM^{2}D fields.

Participants: Girls, young women

Duration: Across the lifespan

Intervention: Johnson & Johnson partnered with non-profit organisations FHI 360 and JA (Junior Achievement) Worldwide (n.d.) to develop an online STEM^{2}D Guide aimed at students, teachers, and others. The guide seeks to enlarge the pool of young people, ages 7–14, especially girls and other under-represented populations, who can aspire to future careers in the STEM^{2}D fields. This "toolkit" contains nine STEM^{2}D activities and best practices that can be used by Johnson & Johnson employees and other volunteers working with young people in classrooms, in out-of-school learning environments, and at community events. Through these partnerships, Johnson & Johnson and its partners intend to reach one million girls by 2020.

Outcomes: The WiSTEM^{2}D programme is included here as an example of a large-scale industry-sponsored gender initiative that is deserving of closer investigation and thorough evaluation. (See O'Connell, 2019, for early indications of programme impact.)

Summary

Although small in number, the set of STEM education interventions displays a rich cross-section of intervention types including online mentoring, in-school and out-of-school modalities, and industry interventions. The interventions range from small to large in terms of participants and effectiveness/evidence is supported by strong statistical analysis in at least 2 cases. The STEM schools intervention is an outlier but the findings are worth consideration at the ***school*** level of the STEM ecosystem. The interventions are mainly concerned with ***learners'*** self-efficacy outcomes, and this is consistent with the findings of the wider review.

8.2.2 Mathematics Education Interventions

Interventions in the mathematics domain included in-school, classroom-based strategies (n=14), out-of-school workshops, summer schools and homework clubs (n=10) or a combination of both in-school and out-of-school settings (n=5). The majority of the intervention studies were based in the US (n=19); two interventions were from Germany and two were from France; one intervention was located in each of Ireland, UK, China, Kenya, Iran and Australia. Sample sizes ranged from 24 participants (Rule, Blaine, Edwards, & Gordon, 2019) to 13,357 participants (Dubetz

& Wilson, 2013). The spread of sample sizes was as follows: 7 studies ($n<100$); 18 studies ($100\leq n<1000$); 2 studies ($n\geq1000$). Therefore, the majority of studies had over 100 participants. The duration of the intervention studies ranged from a one-off classroom-based intervention (Bagès, Verniers, & Martinot, 2016) to a longitudinal study spanning 6 years (Gunderson et al., 2018). The spread of durations for the interventions was: 8 studies ($\leq$ 1 month); 6 studies ($>$ 1 month, $\leq$ 6 months); 6 studies ($>$ 6 months, $\leq$ 1 year); 6 studies ($>$ 1 year); 3 studies (unclear duration). Findings from studies with short durations, particularly those conducted as a once-off event, should be interpreted cautiously in terms of the effectiveness of the interventions.

Turning now to consideration of the participants in these studies, the majority of the interventions in the mathematics domain were aimed at post-primary level (n=16). There were 5 studies at primary level, 3 studies at early childhood level, 2 studies at university level and 3 studies that were aimed at multiple education levels (i.e., early childhood/primary, n=2; and primary/post-primary, n=1). At post-primary level, all but one study involved students, either solely (n=11) or with their parents (n=2) or in-service teachers (n=2). The only intervention not involving students as participants was a year-long study aimed at combating attributional bias for a sample of in-service teachers (Espinoza, da Luz Fontes, & Arms-Chavez, 2014). Seven post-primary level studies were conducted in school, 6 studies were out-of-school interventions and 3 studies combined in-school and out-of-school activity. All studies at primary level involved student participants and two of these studies also involved their parents. No studies at primary level involved teachers as participants. Similarly to post-primary level studies, interventions at primary level involved in-school studies (n=2), out-of-school studies (n=2) and combined in-school and out-of-school (n=1). All early childhood studies involved children, with one also involving their parents and another involving pre-school teachers. Two of the early childhood studies were conducted at home and one was conducted at pre-school. Both university level studies involved students only and were conducted in the university setting.

A variety of methodologies were employed by the research studies in evaluating the interventions in the mathematics domain. Quantitative data collection was a feature of nearly all studies, involving methods such as testing of knowledge or skills, affect scales or other forms of quantitative surveys. Some studies also collected qualitative data in the form of focus groups, interviews, observations, written essays or qualitative surveys. Not all studies were explicit in whether pre- and post-testing occurred and this could only be determined to have been conducted in 11 studies, with 3 of these also carrying out tests during the intervention period (Blackwell, Trzesniewski, & Dweck, 2007; Espinoza et al., 2014; Naizer, Hawthorne, & Henley, 2014). The types of data collected in evidencing effectiveness of interventions were as follows:

- Knowledge/aptitude/skills: 19 studies collected data related to students' mathematics knowledge, problem-solving, mathematics aptitude or spatial skills.
- Confidence/self-rating: 6 studies collected data related to participants' confidence/self-efficacy/self-concept/self-rating with regards to mathematics.

- Interest: 6 studies involved measures of participants' interest in mathematics and/or STEM; 4 studies measured vocational interest or future study interests.
- Stereotypes: 4 studies measured participants' perceptions of gender stereotypes or perceived stereotype threat.
- Attitude: 3 studies collected data regarding participants' attitudes to mathematics and/or other STEM subjects (1 of these studies measured attitudes to toys and specifically Lego).
- Role models: 3 studies involved participants' assessment of presented role models in mathematics/STEM and/or participants' identification with the role models.
- Usefulness: 2 studies examined participants' perceptions regarding the usefulness/utility of mathematics/STEM.
- Motivation: 2 studies collected data on participants' motivational frameworks.
- Attributions of success/failure: 2 studies measured participants' attributions for success/failure in mathematics (1 measured teachers' attributions of student success/failure and 1 measured students' attributions of their own success/failure).
- Engagement: 1 study measured participants' engagement with mathematics.
- Study habits: 1 study collected data regarding students' study habits.

Related to the type of data being collected in the intervention studies is the question of what the interventions were aiming to do. With regards to the mathematics discipline, the aims and outputs of interventions were classified in terms of ***affect*** (n=21), ***knowledge*** (n=16) and ***behaviour*** (n=5). Some intervention studies had only a single classification, while others had multiple aims such as both increasing self-efficacy (affect) and improving knowledge (e.g., Ogle, Hyllegard, Rambo-Hernandez, & Park, 2017). The affect classification was applied to interventions aimed at improving confidence, interest, motivation and other related variables, as well as those aiming to alter participants' perceptions of gender stereotypes or attributions for success/failure in mathematics. The knowledge classification was applied to interventions that aimed to improve mathematics knowledge in terms of improved grades or test scores, interventions related to impacting participants' spatial skills or interventions related to reducing the gender gap in mathematics achievement. Finally, the behaviour classification was applied to interventions that aimed to change behaviours of participants, mainly in terms of uptake or vocational interest in mathematics and/or STEM subjects/ courses but also interventions aiming to change behaviour of participants in the classroom (e.g., motivational related behaviour, as seen in Blackwell et al., 2007). An overview of a selection of the interventions and their effectiveness in terms of changes to affective, knowledge, and behavioural outputs is provided here, with a focus on interventions that had more stringent methodologies and clarity in reporting aims, theoretical frameworks, durations and evidence of impact of the interventions.

Rozek, Hyde, Svoboda, Hulleman, and Harackiewicz (2015) conducted an intervention aimed at increasing the mathematics and science utility-value (***affect***) of a sample of parents with the intention of increasing mathematics and science course taking (***behaviour***) of those parents' post-primary school-age children in line with Eccles's expectancy-value theory (Eccles et al., 1983). Conducted over a 2.33-year period, the intervention included distribution of brochures and provision of a website for parents in the experimental group, focused on the usefulness of mathematics and science for adolescents. Rozek et al. reported an increase in mathematics and science course taking (***behaviour***) for high GPA girls and low GPA boys in the experimental group; an increase in mothers' (only mothers assessed) mathematics and science utility-value (***affect***); higher perceptions by students of parental mathematics and science value (affect); and increased mathematics and science value on the part of students (***affect***).

Bagès et al. (2016) examined the effect of role-models (hard-working, gifted or no explanation for success) on post-primary students' performance in mathematics (***knowledge***), drawing on theories of malleable intelligence. Bagès et al. found that the students, especially girls, obtained their best performance in mathematics when they were exposed to a role model who indicated how to improve one's skills (i.e., the hardworking role model). Girls performed as well as boys when they were exposed to the hardworking role model and scored lower, compared to the boys, when exposed to the gifted role model or the role model whose success was not explained. The explanation for the role model's success did not impact on boys' performance.

Gunderson et al. (2018) examined the effect of parent-child praise, as observed in the home setting during early childhood, on children's motivational frameworks (***affect***) in primary school. Motivational frameworks are associated with a person's theory of intelligence, that is, the beliefs that are held by a person in explaining academic achievement. An incremental theory of intelligence proposes that intelligence is a malleable trait than can be improved through effort, while an entity theory of intelligence instead reflects a belief that intelligence is a fixed trait or ability. In this study, person versus process praise was considered in the prediction of children's motivational frameworks after a five-year period. An example of person praise (aligned with an entity framework) is: "You must be smart at these problems" and an example of process praise (aligned with an incremental framework) is: "You must have worked hard at these problems" (p. 3). Gunderson et al. report that the praise children in the study received at home between the ages of 14 and 32 months was a significant predictor of children's incremental frameworks at age 7-8 years. Incremental frameworks are characterised by beliefs that intellectual traits are malleable, a preference for challenging tasks, attributing success and failure to effort, and generating strategies for improvement. Children whose parents used more process praise were more likely to endorse beliefs and behaviours associated with an incremental framework. Furthermore, Gunderson et al. found that boys received significantly more process praise than girls, even though boys and girls received the same amount of praise overall. Boys reported more incremental frameworks compared to girls. Parents' own incremental theories of intelligence did not predict the form of praise they used, nor did they predict children's motivational frameworks.

Klibanoff, Levine, Huttenlocher, Vasilyeva, and Hedges (2006) investigated whether the amount of mathematically relevant input in pre-school teachers' speech was related to the growth of children's mathematical ***knowledge*** during the period of one pre-school year. Kilbanoff et al. observed differing levels of mathematical knowledge among the children at the start of the pre-school year, with children from middle or high SES backgrounds having higher knowledge than children from low SES backgrounds. They found that pre-school teachers varied dramatically in the amount of mathematics talk they provided in the pre-school classroom and their results indicate that the amount of pre-school teachers' mathematics talk was significantly related to the growth of young children's conventional mathematical knowledge over the course of the year. Although this was not an experimental study, the clear positive relationship between pre-school teachers' mathematical talk and children's mathematical knowledge over an extended time period has implications for the preparation and professional development of early years practitioners and primary school teachers.

Blackwell et al. (2007) followed two cohorts of students through lower post-primary school (junior high school) to examine the relation of theory of intelligence (***affect***) to longer term achievement (***knowledge***) trajectories. Their research also involved an intervention with the second cohort of students, focussing on lower-achieving students, to determine whether teaching an incremental theory of intelligence can reverse a declining achievement trajectory. Their research also aimed to assess whether these students' ***behaviour*** changed in response to the incremental intervention by examining teachers' spontaneous reports of students' behaviour. In studying the first cohort of students over a 2 year period, Blackwell et al. found that students with a malleable, incremental theory of intelligence affirmed learning goals more strongly, and were more likely to believe that working hard was necessary and effective in achievement, than were students who thought that their intelligence was fixed. Furthermore, they were more likely to make fewer ability-based, helpless attributions when faced with the prospect of setbacks. Nearly 2 years later, students who endorsed a strong incremental theory of intelligence at the beginning of post-primary school (junior high school) were outperforming those who held more of an entity theory in mathematics. For cohort 2, which employed the intervention with lower-achieving students, Blackwell et al. report that teaching a malleable theory of intelligence was successful in enhancing students' motivation in their mathematics class, according to teacher reports and, within a single semester, the incremental approach appeared to have succeeded in halting the decline in mathematics achievement.

8.2.3 Science Education Interventions

There are 39 studies selected as effective science interventions or large-scale science studies that have generated well-evidenced recommendations for future interventions. These vary greatly, however, in their scope, their focus, their sample size, and how they determined the impact of the interventions they discuss. For example, the number of participants in each study varied from 23 to 20,000. The spread of sample sizes (for those publications in which the sample size was reported) was as follows: 10 studies with $n<100$; 17 studies with $100 \leq n < 1000$; and 6 studies with $n \geq 1000$. The duration of the interventions also varied considerably, ranging from one lesson to more than 10 years for some longitudinal studies. There were 14 interventions that lasted less than 1 month; 4 of duration between 1 and 6 months; 5 of duration between 6 and 12 months; and 5 lasting more than 1 year. The rather high proportion of short interventions is concerning, since it must be difficult to decide whether such activities are sustainable over time and continue to deliver the desired benefits.

More than half of the interventions were aimed at the level of post-primary school education (24 studies), with 8 targeting primary school education, 2 early childhood education, and 2 further education. This pattern might reflect the existence of a stronger emphasis on science education in the post-primary school curriculum than in primary school in most countries. Participants in these studies were usually children or students (26 studies), and less often children/students with teachers (8 studies), children and parents (2 studies) or children/students with teachers and parents (2 studies).

The majority (62%) of the studies were conducted in the US (n=13) or UK (n=11); 3 studies were carried out in Ireland; 2 studies were located in Taiwan and 2 in France; and 1 study came from each of Scotland, Sweden, Germany, Switzerland, Norway, and Nigeria. In addition, 1 study involved a large number of countries across the EU in documenting gender-based initiatives in STEM.

It is important to recognise that science is multi-disciplinary, consisting of the three major disciplines of biology, chemistry and physics, as well as other subfields, such as environmental science, biochemistry, agricultural science, and so on. Some studies focus on science as one subject, usually when dealing with it in the context of science as an integrated primary or lower secondary-level subject. However, it is notable that the main focus of most of the science studies is in the area of increasing females' uptake and/or achievement in physics. This is not surprising, given that, in general, physics is the subject with the greatest gender imbalance of the main science disciplines. This major gender-inflected change in uptake is noticeable once students have choice in the science subjects they take, for example, after Junior Cycle (or the international equivalent).

Some reports, such as the ASPIRES2 study from the UK (Archer, Moote, McLeod, Francis, & DeWitt, 2020), focus on all the sciences and, to a lesser extent, other STEM subjects such as mathematics and technology. However, they are mindful of the nuances of how gender imbalance plays out across the different STEM subjects. This leads to an important general observation that it is unlikely that the same interventions to support gender balance are either required, or would suit, all STEM disciplines/school subjects. There are different factors at play: for example, in Ireland, mathematics at Senior Cycle is generally not a choice subject within schools, where the sciences and technology subjects are. Questions of access to STEM subject curricula might also be an important consideration, where "access" refers not only to the existence of a subject specification (such as Ireland's new Leaving Certificate specification for computer science) but also to whether or not an established Leaving Certificate subject is offered in a school (e.g., physics is not offered in all Irish post-primary schools).

Because of the strong focus on improving the gender balance in physics, it is appropriate to give some weight to studies in this field. In particular, the Institute of Physics (IOP) as the professional body/learned society for physicists has been heavily investing in investigations and interventions to improve gender balance at school for some years, primarily in the UK but also in Ireland. In terms of research-based interventions into improving uptake and achievement in STEM subjects by girls, the IOP is at the forefront for science subjects. There is no comparable programme of interventions for chemistry or biology that are as sustained, as multi-faceted or as wide-ranging. If another national professional organisation (outside Ireland or the UK) is making a similar concerted effort to enhance the uptake of physics or other sciences by girls, it has not emerged through this systematic literature review. The implication is that, from an anglophone perspective (this literature review did not review the literature published in languages besides English, so there may potentially be such work going on that has been published in journals written in other languages), the IOP's work in this arena is the most significant body of work internationally in promoting gender balance in science subjects.

Of the 39 science studies included in Stage II of this systematic review, 7 are reports, summaries or literature reviews commissioned by the IOP since 2006. The IOP has also published other reports, but these 7 (listed below) capture the main IOP studies/projects on promoting gender balance, and the findings from them.

Murphy, P., & Whitelegg, E. (2006). Girls and physics: Continuing barriers to 'belonging'. *The Curriculum Journal*, *17*(3), 281-305. (Note: the IOP also published this literature review, which it commissioned, as a report)

Daly, A., Grant, L., & Bultitude, K. (2009). *Girls into physics: Action research report.* Institute of Physics and Department for Children, Schools and Families. http://www.iop.org/education/teacher/support/girls_physics/action_research/page_41736.html (This is the evaluation report of the 'Girls into Physics: Action Research' programme. Note also, this programme was informed by the *Girls and physics* literature review listed above.)

Institute of Physics. (2013). *Closing doors: Exploring gender and subject choice in schools.* http://www.iop.org/publications/iop/2013/closingdoors/

Institute of Physics. (2015). *Opening doors: A guide to good practice in countering gender stereotyping in schools.* http://www.iop.org/publications/iop/2015/file_66429.pdf

Institute of Physics. (2017). *Improving gender balance: Reflections on the impact of interventions in schools*. http://www.iop.org/publications/iop/2017/file_69171.pdf

Skills Development Scotland. (2018). *Review of Improving Gender Balance Scotland*. https://www.skillsdevelopmentscotland.co.uk/media/44705/review-of-improving-gender-balance-2018.pdf

McLoughlin, E., O'Neill, D., & Fagan, G. (2020). *Improving Gender Balance Ireland (2017-2019): Final Report.* CASTeL, Dublin City University.

Improving Gender Balance (IGB) is the IOP's current large scale intervention, which has emerged from an evidence base built up over a decade, as indicated by the earlier reports listed above. The IOP has conducted or is conducting IGB interventions in Scotland, Ireland and England. The IGB England intervention is the most recent, and there are no findings yet published. These interventions are based broadly on the IOP's IGB design principles (see Institute of Physics, 2017, which summarises impacts from all previous programmes, and from a pilot implementation of the IGB project), although they differ somewhat in scale and in mode of implementation.

Skills Development Scotland (2018) partnered with and funded the IOP to deliver ***Improving Gender Balance Scotland*** (IGBS). This was a 3-year action research pilot project, completed in March 2018, which was designed to align with the Scottish Government's Youth Employment strategy. The project aimed to identify and address issues around gender imbalance in subject and career choice as well as workplace behaviours. These issues were acknowledged to arise from deep-rooted cultural norms and values that lead to stereotypical views on the part of parents, teachers, and employers. The project was designed to raise awareness of these gender *stereotypes* and to create interventions to address them.

The IGBS project's partnership with Education Scotland was vital as it created synergies with their National STEM project and helped maximise the potential for mainstreaming this activity in the long term. IGBS worked with six school clusters (a secondary school and its associated primary schools and Early Learning Centres) to ensure both coherence across stages and long-term sustainability. By working with clusters of providers at different educational levels, the project aimed to achieve an embedded and sustainable approach to tackling gender imbalance in subject uptake and education pathway choices, with a focus on STEM subjects. Addressing gender stereotypes at an early stage and keeping this message consistent was the priority. A wide range of activities and interventions was developed in partnership with these clusters:

- teacher/staff surveys inviting reflection on how schools were dealing with gender issues;
- continuing professional development providing unconscious bias training;
- efforts to develop more inclusive teaching practices;
- parent/pupil information evenings;
- auditing of resources such as subject choice booklets to identify how gender was presented;
- development of lessons to challenge learners' understanding of gender stereotypes and unconscious bias.

As the IGBS project evolved over the three years, the team increasingly engaged with a wide range of other bodies and influencers, such as local authorities and colleges. All schools consulted were engaged in the project at the senior level. Leadership from head teachers, deputy head teachers and faculty heads was essential in driving the agenda. The project was extensively evaluated with evidence indicating that it met its objectives. It was successful in engaging a large number of schools and other organisations to take steps to address the gender imbalance in subject participation and subject choices, and to create partnerships, clusters and networks that facilitated discussion and action. The transitional interaction and work carried out between early years, primary school, and secondary school was highlighted and provides a template for similar approaches elsewhere. Participants reported increased knowledge of approaches that can be taken to address gender imbalance issues and confidence in their ability to tackle these issues.

The ***Improving Gender Balance Ireland*** (IGBI) project (McLoughlin, O'Neill, & Fagan, 2020) was led by CASTeL at Dublin City University and conducted from 2017-2019, beginning with 7 secondary schools in Phase I and adding a further 21 secondary schools in Phase II. The objectives of the project were to (i) deepen science *teachers'* confidence and content knowledge for teaching physics, (ii) adopt a whole school approach to addressing unconscious bias and gender-*stereotyping* and build confidence and resilience for students, particularly girls, to continue with physics, and (iii) increase awareness of STEM and careers in STEM (*interest*). The project worked collaboratively with schools, teachers and students, as well as external stakeholders of STEM education in Ireland, including IOP, Science Foundation Ireland, Department of Education Inspectorate, State Examinations Commission, National Council for Curriculum and Assessment, Junior Cycle for Teachers (Science), Professional Development Service for Teachers, and EPI*STEM at the University of Limerick. Central to the intervention were teacher and student workshops on gender stereotyping and unconscious bias, and science workshops for teachers that developed content knowledge for teaching physics while modelling inquiry-based pedagogy. Evaluation of the impact of the project provided evidence of improvement in teachers' self-reported confidence and competence in teaching physics at Junior Cycle.

The IOP (2017) has published a report that summarises the impact of its Improving Gender Balance project in the UK. The project ran from 2014-2016 and involved 20 partner schools that participated in one of three strands, focusing on either improving girls' confidence and resilience (8 schools), working in the physics classroom (8 schools), or a whole school approach to improvement (4 schools). A further 6 schools participated in an additional pilot project that combined these different strands according to individual schools' needs. All of these interventions had a positive impact, typically documented via teacher self-reports (e.g., perceptions of student interest and confidence, or of changes in their teaching practice) and student self-reports (e.g., increased confidence, enjoyment, awareness of gender issues). In analysing the overall impact of these studies, the report recommended implementing unconscious bias training for teachers and raising students' awareness of gender stereotypes. It also recommended adopting a whole-school approach to gender balance, while acknowledging the barriers to this approach (e.g., time commitment, leadership support, staff buy-in, teacher beliefs, breaking down academic silos, managing schools' competing priorities, staff turnover, and parental expectations).

While the Institute of Physics projects have focused on addressing gender stereotypes, other research has investigated the broader concept of physics identity. Hazari, Sonnert, Sadler, and Shanahan (2010) developed a physics *identity* framework that combines the dimensions of (1) recognition by others as being a good physics student), (2) interest in physics, (3) belief in ability to perform physics tasks, and (4) belief in ability to understand physics concepts. They investigated how strongly this physics identity indicator was related to a choice to pursue a physics career, and what factors from secondary school physics experience predicted students' physics identity indicator. Although not an intervention study, this large-scale (n=3829) US survey yielded useful findings that could inform policy and practice. Not only was physics identity found to predict physics career choice, but physics identity was in turn predicted by a range of secondary school physics experiences such as a focus on conceptual understanding, real world/contextual connections, students' active engagement in lessons, and having an encouraging teacher. However, the only predictor that had a differential gender effect was the discussion of female under-representation in their high school physics class: this was positively related to females' physics identity indicator but not to males'.

Also supplementing the IOP projects is research on social-psychological factors that influence a sense of *belonging* experienced by females in physics. Lewis, Stout, Pollock, Finkelstein, and Ito (2016) conducted a literature review on interventions in this area in the context of women in higher education; however, the following conclusions and recommendations from their review could easily be adapted for secondary school students.

1. Identify and temper cues that perpetuate the "geeky" scientist stereotype: avoid sending implicit messages in selection of resources and examples.
2. Openly endorse effort and hard work over brilliance: encourage an incremental theory of intelligence that treats mathematical and science skills as malleable rather than fixed.
3. Send messages that concerns about belonging are normal and fade with time: role models can share their experiences and strategies for success.
4. Consider the social context constructed in the classroom: maximise opportunities for students to make social connections.
5. Consider the broader social context students are a part of outside the classroom: affirm the value of students' outside social resources and emphasise benefits of science to society.

Most physics interventions have sought to address barriers to gender balance at the ***learner*** level, focusing especially on issues of stereotyping and identity. ***School***-level influences were also addressed in some science education studies. In Sweden, for example, Eliasson, Karlsson, and Sørensen (2017) investigated the types of questions posed by lower secondary science teachers and patterns of male and female students' responses. They found that *teachers* overwhelmingly posed closed questions that could be answered with short factual responses rather than open questions that invited discussion, speculation and sharing of ideas. Boys responded to a significantly greater share of the closed questions, indicating that they dominated the classroom communication space. On the other hand, open questions elicited an equal share of responses from boys and girls, which suggests that these types of question may invite wider participation of girls.

As another type of ***school***-level influence, performance-oriented approaches to *assessment* can activate the negative stereotype held by girls that they are poor performers in science. Souchal et al. (2014) explained that assessment serves two main purposes in education: to help students learn a subject by providing formative feedback, and to certify achievement by measuring summative performance. These two assessment purposes correspond to the distinction between mastery goals (a desire to increase one's learning) and performance goals (a desire to perform well compared to others). In their study involving 193 French secondary school science students, Souchal et al. gave all students the same science test, but different groups of students received different instructions about whether the purpose of the test was to help them learn or to compare their performance with others. The performance-oriented assessment condition reduced the performance of girls, while in the mastery-oriented assessment condition girls and boys performed at a similar level. The recommendation from this study is that assessment should be presented as a learning tool for improving mastery rather than as a tool for measuring, comparing, and selecting students.

Rather than reporting on a single ***school***-level intervention study, Baker (2013) synthesised research findings on a range of instructional strategies “that teachers can use to enhance achievement, self-efficacy, and participation of girls in science” (p. 14). These strategies are primarily concerned with *curriculum* and *teaching* and are summarised as follows:

1. Early science instruction beginning in pre-kindergarten
2. Relevant curriculum that addresses girls’ interests and provides many opportunities for genuine inquiry and tinkering experiences
3. Greater emphasis on physical science and the use of computers
4. Integration of reading and writing in science
5. Careful attention to how groups are formed
6. Activities that build self-efficacy (increase mastery experiences, give positive messages about competence, offer vicarious experiences)
7. Appropriate role models (near-age peers; female teachers)
8. Voiced and unvoiced messages that science is for everyone
9. Student-centred teaching

The final report of the ASPIRES2 study (Archer et al., 2020), conducted in the UK, provides valuable insights into young people’s science and career aspirations from ages 14 to 19. This was a large, national mixed-methods study that extended previous research conducted with the same cohort of young people who took part in the first ASPIRES project at ages 10 to 14. Findings from the original ASPIRES and the ASPIRES2 projects draw on 40,000 surveys and 660 interviews with young people and parents/carers. Patterns of aspirations were found to be relatively stable from ages 10 to 18. Young people’s science aspirations were persistently low, but not a consequence of low interest in science, lack of family support, or negative views about scientists. Instead, factors influencing science identities and aspirations were grouped into three themes:

1. Capital-related inequalities: especially young people’s science-related knowledge, attitudes, experiences and social contacts (for an explanation of *science capital* see Archer, Dawson, DeWitt, Seakins, & Wong, 2015)
2. Dominant educational and social representations of science: young people associate science with “cleverness” and “masculinity”
3. Educational factors and practices: teacher qualifications, experience, attitudes and behaviours; nature of the science curriculum; young people’s experience of school science; careers education.

Responding to these clusters of influences, the ASPIRES2 report recommends actions that build science capital, address educational practices, and challenge dominant representations of science. These actions align with the ecological model adopted by this systematic review, as they address influences at the levels of ***learner***, ***family***, ***school***, and ***society***.

8.2.4 Engineering, Technology, and Computer Science Education Interventions

Interventions in these disciplines comprised after school programmes/clubs, summer camps, workshops, outreach programmes (often involving role models and mentors), and some in-school or classroom-based strategies. Evidence of their effectiveness was investigated using a range of research methods including surveys, interviews, tests, participation data, and observations. The participant group sizes varied from 20 to 15,000, with a spread of sample sizes as follows: 17 studies ($n<100$); 12 studies ($100\leq n<1000$); 4 studies ($n\geq 1000$). Therefore, the majority of studies (n=17) had fewer than 100 participants.

The duration of the intervention studies ranged from a one-off classroom-based intervention, such as 20 minutes playing a game (Master, Cheryan, Moscatelli, & Meltzoff, 2017) to a longitudinal study spanning 7 years (Dell et al., 2011; Ivey & Palazolo, 2011). The profile of study duration was as follows: 10 studies (≤ 7 days); 4 studies (< 4 weeks, 2 studies ≤ 6 months); 1 study (> 6 months, ≤ 1 year); 1 study (> 1 year); 20 studies (unclear duration / no detail).

With regard to the participants in the intervention studies, around two-thirds (n=31) targeted post-primary school level education, with 6 aimed at primary school level, 3 at early childhood, 2 at further education, and the remainder at a mixture of educational levels. In these studies a substantial majority of participants were students only (n=38), with most of the remainder involving students/children interacting with adults such as teachers, parents or mentors (n=6).

The majority of the intervention studies were located in the US (n=33), with 1 or 2 studies sourced from countries including Taiwan, Israel, Sweden, Australia, Germany, Finland, Norway, Belgium, Spain, and France.

Significant emphasis was placed on increasing ***learners'*** interest in studying and pursuing careers in engineering, technology and computer science. To address this goal, various types of outreach programmes were reported, often involving after-school activities, summer camps or clubs. Many of these activities brought girls into contact with female undergraduate students or university faculty or professionals in these fields who acted as *role models and mentors*. For example, Ivey and Palazolo (2011) reported on their evaluation of the Girls Experiencing Engineering programme, conducted by the University of Memphis, Herff College of Engineering since 2004. This programme provides an intensive one-week hands-on engineering experience for middle school girls and their mathematics and science teachers, increasing students' awareness of study and career opportunities in engineering and providing teachers with new pedagogical methods. Female engineering professionals participate as guest speakers providing insights into their careers. The programme has been systematically evaluated over time and there is evidence of its success in improving girls' attitudes, confidence, and understanding of engineering as a career. Despite challenges in maintaining contact with past programme participants, the evaluators have also gathered survey data confirming the programme has influenced participants to consider and pursue college majors in the STEM fields. The programme's organisers report that survey responses from the female participants indicated they did not believe their parents supported a career in engineering for them, and this has led to a goal of broadening the knowledge of *parents* about career opportunities in engineering.

Weavers et al. (2011) described a similar engineering outreach activity in the form of an annual, week-long day camp aimed at middle school (8th grade) girls. The Future Engineers Summer Camp is run by engineering academics at Ohio State University and introduces the participants to college-level engineering concepts through "design and build" activities. The camp involves students in interactions with practising engineers as well as faculty members and graduate students. The aims are for the girls to learn about engineering, develop positive attitudes and aspirations towards mathematics, science, and engineering, and meet female peers with similar interests so they can experience that it is socially acceptable to like these subjects. This programme has been thoroughly evaluated using a range of strategies: evaluation cards that seek immediate feedback on participant satisfaction; a retrospective survey seeking self-assessment of changes in participants' knowledge, skills, attitudes and behaviour; focus groups that probe these self-assessments more deeply; and a past participant survey that aims to track girls' continuing aspirations towards engineering until they finish high school. Similar to the programme outlined by Ivey and Palazolo (2011), it was difficult to maintain contact with past participants in order to conduct the longitudinal aspect of the evaluation and this has now been discontinued. Nevertheless, analysis of evaluation feedback indicated that the programme increased girls' knowledge in engineering and improved the already-positive attitudes and aspirations they had at the outset.

Mentorship and role models also figured in interventions involving information and communication technology. Modekurty, Fong, and Cheng (2014) reported on a one-week summer camp on computing and robotics leadership for middle school girls, delivered by the University of California. The camp was led by female college students who acted as coaches with assistance from high school female assistant coaches. The participants learned the basics of robotics, principles of engineering and essentials of C/C++ programming, as well as life skills such as teamwork, presentation skills, and leadership skills. Female professionals in various science and engineering fields met with the participants to help them imagine a future career in STEM. The coaches and assistant coaches continued to mentor the girls over the subsequent school year. A survey-based evaluation of the programme provided evidence of participant satisfaction, increased confidence in the fields of robotics and programming, and interest in pursuing study and careers in these fields.

School-based interventions designed to improve the gender balance were less common than out-of-school outreach programmes in engineering, technology, and computer science education. However, two examples provide insights into effective *curriculum* design for school-based implementation. Sullivan and Bers (2012) introduced the TangibleK Robotics Program to kindergarten children to investigate whether girls and boys were equally successful in a series of building and programming tasks. The Program comprises a specially designed six-lesson curriculum that introduces powerful ideas from computer science (the engineering design process, robotics, control flow by sequencing and by special instructions) in a developmentally appropriate way. Lessons were delivered to three classes of children by three kindergarten teachers who had received training in the TangibleK Program. Children's learning achievements were rigorously assessed via observation, conversation and interview, and analysis of what they built. The evaluation found that the TangibleK Robotics Program was, for the most part, equally accessible to girls and boys and that children of both genders were able to successfully complete the curriculum and the robotics project. Boys scored significantly higher than girls in 2 of the 19 task components that were assessed across the six lessons, but there were no statistically significant differences between girls and boys in other task components or in any debugging tasks across all lessons. This study suggests that it is possible to successfully introduce girls to robotics and programming in early childhood, before gender stereotype threat begins to cause anxiety and lack of confidence in the STEM fields.

The second example of a ***school***-based *curriculum* intervention is a study by Purdue University researchers Douglas, Mihalec-Adkins, and Diefes-Dux (2014), which developed and implemented an early primary school (grades 2-4) engineering education curriculum. Teachers were provided with professional development in a week-long academy that discussed technology, the work of engineers, and the engineering design process. They then committed to implementing engineering lessons for a minimum of two years, with attendance at a three-day follow-up academy after the first year to provide further support and development. The 818 students participating in this study were given a validated survey that measures engineering *identity* development amongst pre-adolescent students. Boys and girls both significantly improved in their identification as potential engineers after experience with hands-on engineering lessons. This is an encouraging finding as one of the main rationales for including engineering in the school curriculum is to inspire learners. The researchers expressed the hope that the introduction of the Next Generation Science Standards in the US will provide meaningful learning experiences with engineering for students from early primary school.

The importance of the ***school*** *curriculum* in encouraging and supporting female participation in engineering, technology and computer science education was highlighted in an Australian study reported by Zagami, Boden, Keane, Morton, and Schulz (2015). They conducted a Delphi study to identify issues related to the low levels of female participation in computer science. A Delphi study uses iterative discussions and surveys to structure consensus analysis of an issue by key stakeholders – in this case, academics, professional association leaders, leaders of initiatives promoting female participation in computer science, IT companies, teachers, and students. The Delphi process, conducted over a 5-month period, identified four strategies considered to be most promising: (1) engage girls in the Digital Technologies school curriculum; (2) address parental preconceptions and influences; (3) provide role models and mentors; and (4) set up coding clubs for girls. The researchers noted that these strategies are no different from those that have been used with some success in mathematics and science to encourage females' participation. Yet in computer science, and also in engineering, these same interventions have not led to similar improvements in the participation of girls. They concluded that this difference might be explained by a key factor – how the disciplines are treated in the school curriculum. They argued that "mathematics and science education have a strong mandatory curriculum framework stretching from school entry to the end of compulsory schooling" (p. 11) and this provides a scaffold for supporting interventions and sustaining any benefits achieved. However, in Australia, computing and engineering lack a developmental curriculum in the school context, with only uncoordinated or one-off courses representing extra-curricular initiatives that place them "outside" the norm. The researchers speculated that such arrangements may contribute to the decline in young adolescents' engagement with computing.

9. Matrix of Barriers and Effective Interventions

A master spreadsheet was created that records details of the 122 effective interventions. Separate worksheets in the spreadsheet display different aspects of the literature. The first worksheet provides a summary of frequencies of different interventions by discipline (similar to Table 8). The second worksheet reproduces this summary, but it adds a feature that allows users to click on a discipline and intervention type in order to produce a list of publications relevant to this choice. The next four worksheets correspond to the four disciplines (mathematics, science, STEM, engineering/technology/computer science) and classify publications in these disciplines by intervention type and the other essential features outlined in section 7.3. The next two worksheets map the abstracts of each publication to the ecological framework using appropriate search terms. Subsequent worksheets provide citation details and abstracts for interventions by type and level of the ecological framework.

The master spreadsheet represents a comprehensive, but rather complex, matrix of barriers to gender balance in STEM education and effective interventions addressing these barriers. A more concise spreadsheet matrix has been constructed from the studies discussed in section 8 of this report and is provided as Appendix 2.

10. Key Messages from Stage II: Interventions

This second stage of the literature review identified 122 publications in mathematics, science, STEM, and engineering/technology/computer science education that reported on interventions aiming to improve girls' participation, achievement and progression in STEM studies, or on large-scale surveys and literature reviews that yielded actionable insights on potentially effective interventions. Similarly to Stage I, an important message from the second stage of the literature review is **that there is no single type of intervention that can be identified as the preferred approach to achieving gender equity in STEM education**. However, the review has generated some consistent messages that have potential to shape policy and practice in this field, especially in relation to the concept of building a multi-level, interconnected STEM ecosystem as proposed by Ireland's *STEM Education Policy Statement* (Department of Education and Skills, 2017).

10.1 Challenges in Identifying Effective Interventions

This review used a methodology in which published reports on "effective" intervention studies were considered to be a subset of the larger set of studies that investigated gendered barriers to STEM participation. Thus, it was not surprising to find that the selected intervention studies were much less numerous (n=122) than the complete set of studies identified in Stage I (n=943). Even so, some reports that were classified as intervention studies instead examined student attitudes and aspirations over time and tried to link these to existing factors influencing participation. Nevertheless, there is undoubtedly value in attending to large-scale national studies of this type, especially those that have gathered longitudinal data. These studies typically make well-founded recommendations for policy and practice rather than report on "what works" (e.g., ASPIRES2).

We developed criteria for what counts as an "effective" intervention, based on publication status (preferably peer reviewed), sample size (≥20 participants), explicitly detailed methodology, and a description of how effectiveness was evaluated. However, even those studies classified as "effective" according to these broad criteria often did not provide adequate information, for example, on the number and type of participants, nature and duration of the intervention, and evidence of effectiveness. It was also rare to find any information on the longer-term impact of an intervention.

Evidence of effectiveness of interventions varied in both form and quality: the selected studies typically investigated changes in participation, attitudes, beliefs, and aspirations, with less attention to changes in achievement and behaviours. In developing strategies and actions arising from this literature review, it will be important to decide on ***how to collect evidence of their effectiveness***, and indeed on ***what counts as "effective".*** In other words, what is the outcome variable we want to change? Kirkpatrick and Kirkpatrick's (2006) framework is useful in this regard because it draws attention to the different levels of impact that are possible – reaction, learning, behaviour, and results. Each successive level seeks increasingly robust evidence, with the last level oriented to systemic or societal impact. Each level is also more challenging to evidence than the last.

10.2 Characteristics of Effective Interventions

Rising above the detail of the individual interventions discussed in this review, we can identify a set of more general messages summarised as the ***shifts*** shown in Table 9.

Despite the strong quantitative emphasis in our analysis on interventions targeting individual learners' interest, engagement, motivation, and enjoyment, we would caution against recommending interventions that unintentionally position children and young people as "the problem" that needs to be "solved", for example, by endeavouring to change their negative attitudes and low aspirations or by offering STEM career information. Instead, we emphasise once more the interconnected nature of factors influencing young people's participation in STEM, and the need to reconsider how families, schools, and societal institutions in the STEM ecosystem think and act in relation to STEM education and careers.

Shift away from ...	Shift towards ...
STEM education interventions mainly aimed at post-primary school students	Inclusive STEM education programmes that start in early childhood and continue through adolescence into adulthood, in both formal and informal educational settings
One-off or short-term interventions that lack connections to a broader purpose or programme	Long term, coordinated, multi-agency partnerships between families, schools, higher education, government departments, learned societies, business and industry, community organisations
Seeking to change girls' attitudes, beliefs, and behaviours	Seeking to change STEM education structures, practices, and the representation of STEM in wider society, that create barriers to gender-balanced participation

Table 9
Proposed Shifts in Emphasis to Achieve Gender Balance in STEM Education

Within this STEM ecosystem it is critically important that interventions targeting one barrier or level are ***aligned*** with other elements of the ecosystem. For example, an intervention designed to build girls' STEM capital by linking them with mentors and role models in out-of-school activities might not have the desired long-term effect unless it is aligned with school subject offerings and timetabling constraints, high-stakes assessment practices, teachers' pedagogical approaches, and family values and funds of knowledge. All elements of the STEM ecosystem need to be developed and strengthened in coordinated fashion. Another aspect of alignment worth considering involves the extent of curriculum coherence and articulation across the transition points that young people experience in their education. Evidence from our review suggests that a strongly articulated, developmental curriculum in the separate STEM disciplines (science, technology, engineering, mathematics) provides not only a sense of continuity for students but also scaffolding to support extra-curricular interventions. Alignment also assumes equitable access to the curriculum. We would therefore argue that there is a strong equity imperative in ensuring that all students have access to the widest range of STEM subjects in schools and to teachers who are appropriately qualified to teach these subjects.

11. Towards Action

Based on the findings of this systematic review, we propose that a worthwhile purpose for the STEM education enterprise is to ***develop STEM capital through formal and informal education***. This in turn requires ***developing, strengthening, and organising the entire STEM ecosystem***.

The STEM ecosystem operates at the interconnected levels of learner, family, school, and society. Our analysis of the literature on effective interventions was largely silent on societal level interventions, even though contextual factors related to "society, legislation and policies" were mentioned in one-third (40/122) of the intervention studies we identified. However, it may be useful to consider the recommendations of the US National Academies (2020) report, which placed significant emphasis on policy change in formulating the following recommendations:

1. Drive transparency and accountability: Articulate, monitor, and deliver on measurable goals and benchmarks.
2. Adapt data-driven approaches to address underrepresentation of women: Disaggregate data on barriers by discipline and level of education and recognise that interventions may need to be contextualised to discipline and specific target groups.
3. Reward, recognise, and resource equity, diversity, and inclusion efforts: Offer positive incentives that promote cultural change.
4. Fill knowledge gaps: Although scholarly research has yielded abundant information on causes of gender disparities, critical knowledge gaps remain and require close attention (e.g., understanding strategies and practices that are demonstrably effective).

Following on from this systematic review, decisions about prioritising a response might identify intervention points for maximum effect while customising the response to the Irish context. For example, attention could be given to points where students make subject choices, such as in choosing (or not) to study science in Junior Cycle. The introduction of new subjects, such as Leaving Certificate Computer Science, offers a test bed for investigating and addressing gendered patterns of student engagement. Curricular structures, such as the Transition Year in post-primary education, can also open up opportunities to broaden all students' STEM experiences at school and in extra-curricular programmes, away from a high-stakes assessment environment.

While the longer-term goal of building STEM capital needs to be kept in view, short-term initiatives that contribute to this goal can be pursued at the same time. With this "parallel processing" approach in mind, our systematic review points to the value of targeting two key phases in a young person's educational life:

- Early childhood: to build strong foundations and engage parents in learning at home and at school;
- Early adolescence: to avert disengagement, influence subject choices, and take advantage of a low-stakes assessment environment as an opportunity for broadening students' STEM experiences at school and in informal learning.

Further research is also needed to conceptualise STEM capital and evaluate its development, if this is to be used as a measure of the quality and coherence of Ireland's STEM ecosystem.

12. References

Archer, L., Dawson, E., DeWitt, J., Seakins, A., & Wong, B. (2015). "Science capital": A conceptual, methodological, and empirical argument for extending Bourdieusian notions of capital beyond the arts. *Journal of Research in Science Teaching*, *52*(7), 922-948.

Archer, L., Moote, J., MacLeod, E., Francis, B., & DeWitt, J. (2020). *ASPIRES 2: Young people's science and career aspirations, age 10-19.* London: UCL Institute of Education. Retrieved 6 April 2020 from https://discovery.ucl.ac.uk/id/eprint/10092041/15/Moote_9538%20UCL%20Aspires%202%20report%20full%20online%20version.pdf

Bagès, C., Verniers, C., & Martinot, D. (2016). Virtues of a hardworking role model to improve girls' mathematics performance. *Psychology of Women Quarterly*, *40*(1), 55-64.

Baker, D. (2013). What works: Using curriculum and pedagogy to increase girls' interest and participation in science. *Theory Into Practice*, *52*(1), 14-20.

Blackwell, L. S., Trzesniewski, K. H., & Dweck, C. S. (2007). Implicit theories of intelligence predict achievement across an adolescent transition: A longitudinal study and an intervention. *Child Development*, *78*(1), 246-263.

Bronfenbrenner, U. (1989). Ecological systems theory. In R. Vasta (Ed.), *Annals of child development*, Vol. 6 (pp. 187–249). Greenwich, CT: JAI Press.

Central Statistics Office (2018). *Measuring Ireland's progress 2018*. Retrieved 9 March 2020 from https://www.cso.ie/en/releasesandpublications/ep/p-mip/measuringirelandsprogress2018/introduction/

Committee on STEM Education of the National Science and Technology Council (2018). *Charting a course for success: America's strategy for STEM education.* Retrieved 29 January 2020 from https://www.whitehouse.gov/wp-content/uploads/2018/12/STEM-Education-Strategic-Plan-2018.pdf

Daly, A., Grant, L., & Bultitude, K. (2009). *Girls into physics: Action research report.* Institute of Physics and Department for Children, Schools and Families.

Dell, E., Bailey, M. B., O'Hurley, S., Lilis, R. P., Khol, B., & Garrick, R.D. (2011, June 26-29). *WE-IMPACT: Women in engineering-improving program assessment tools for outreach and retention programs.* Paper presented at the American Society for Engineering Education Annual Conferences & Exposition, Vancouver, BC. Retrieved 23 March 2020 from https://peer.asee.org/we-impact-women-in-engineering-improving-program-assessment-tools-for-outreach-and-retention-programs.pdf

Department of Education and Skills (2017). *STEM education policy statement 2017-2026*. Dublin: DES. Retrieved 30 January 2020 from https://www.education.ie/en/The-Education-System/STEM-Education-Policy/stem-education-policy-statement-2017-2026-.pdf

Douglas, K. A., Mihalec-Adkins, B. P., & Diefes-Dux, H. A. (2014, June 15-18). *Boys' and girls' engineering identity development in early elementary before and after hands-on engineering learning classroom experiences: Research to practice*.

Paper presented at the 121st American Society for Engineering Education Annual Conferences & Exposition, Indianapolis, Indiana. Retrieved 23 March 2020 from https://peer.asee.org/boys-and-girls-engineering-identity-development-in-early-elementary.pdf

Dubetz, T. A., & Wilson, J. A. (2013). Girls in engineering, mathematics and science, GEMS: A science outreach program for middle-school female students. *Journal of STEM Education: Innovations and Research*, *14*(3), 41-47.

Eccles, J.S., Adler, T.F., Futterman, R., Goff, S.B., Kaczala, C.M., Meece, L.J., et al. (1983). Expectancies, values, and academic behaviors. In J.T. Spence (Ed.), *Achievement and achievement motivation: Psychological and sociological approaches* (pp. 75–146). San Francisco, CA: Freeman.

Eliasson, N., Karlsson, K. G., & Sørensen, H. (2017). The role of questions in the science classroom–How girls and boys respond to teachers' questions. *International Journal of Science Education*, *39*(4), 433-452.

Espinoza, P., da Luz Fontes, A. B. A., & Arms-Chavez, C. J. (2014). Attributional gender bias: Teachers' ability and effort explanations for students' math performance. *Social Psychology of Education*, *17*(1), 105-126.

Falco, L.D., & Summers, J. J (2019). Improving career decision self-efficacy and STEM self-efficacy in high school girls: Evaluation of an intervention. *Journal of Career Development*, *46*(1), 62-76.

FHI360 and JA Worldwide (n.d.). *STEM^{2}D resource guide*. Retrieved 23 March 2020 from https://www.stem2d.org/s/STEM2D_RESOURCEGUIDE_COMPRESSED.pdf

Gunderson, E. A., Sorhagen, N. S., Gripshover, S. J., Dweck, C. S., Goldin-Meadow, S., & Levine, S. C. (2018). Parent praise to toddlers predicts fourth grade academic achievement via children's incremental mindsets. *Developmental Psychology*, *54*(3), 397-409.

Hazari, Z., Sonnert, G., Sadler, P. M., & Shanahan, M. C. (2010). Connecting high school physics experiences, outcome expectations, physics identity, and physics career choice: A gender study. *Journal of Research in Science Teaching*, *47*(8), 978-1003.

Institute of Physics. (2013). *Closing doors: Exploring gender and subject choice in schools.* http://www.iop.org/publications/iop/2013/closingdoors/

Institute of Physics. (2015). *Opening doors: A guide to good practice in countering gender stereotyping in schools.* http://www.iop.org/publications/iop/2015/file_66429.pdf

Institute of Physics. (2017). *Improving gender balance: Reflections on the impact of interventions in schools*. http://www.iop.org/publications/iop/2017/file_69171.pdf

Ivey, S. S., & Palazolo, P. J. (2011, June 26-29). *Girls experiencing engineering: Evolution and impact of a single-gender outreach program.* Paper presented at the American Society for Engineering Education Annual Conferences & Exposition, Vancouver, BC. Retrieved 23 March 2020 from https://peer.asee.org/girls-experiencing-engineering-evolution-and-impact-of-a-single-gender-outreach-program.pdf

Kirkpatrick, D., & Kirkpatrick, J. (2006). *Evaluating training programs: The four levels* (3rd ed.). Oakland CA: Berrett-Koehler Publishers.

Klibanoff, R. S., Levine, S. C., Huttenlocher, J., Vasilyeva, M., & Hedges, L. V. (2006). Preschool children's mathematical knowledge: The effect of teacher “math talk”. *Developmental Psychology*, *42*(1), 59-69.

LaForce, M., Noble, E., King, H., Century, J., Blackwell, C., Holt, S., ... & Loo, S. (2016). The eight essential elements of inclusive STEM high schools. *International Journal of STEM Education*, *3*(1), 21. https://doi.org/10.1186/s40594-016-0054-z

Lewis, K. L., Stout, J. G., Pollock, S. J., Finkelstein, N. D., & Ito, T. A. (2016). Fitting in or opting out: A review of key social-psychological factors influencing a sense of belonging for women in physics. *Physical Review Physics Education Research*, *12*(2), https://doi.org/10.1103/ PhysRevPhysEducRes.12.020110.

Marginson, S., Tytler, R., Freeman, B., & Roberts, K. (2013). *STEM: Country comparisons. International comparisons of science, technology, engineering and mathematics (STEM) education.* Melbourne: Australian Council of Learned Academies. Retrieved 29 January 2020 from https://acola.org.au/wp/PDF/SAF02Consultants/SAF02_STEM_%20FINAL.pdf

Master, A., Cheryan, S., Moscatelli, A., & Meltzoff, A. N. (2017). Programming experience promotes higher STEM motivation among first-grade girls. *Journal of Experimental Child Psychology*, *160*, 92-106.

McLoughlin, E., O’Neill, D., & Fagan, G. (2020). *Improving Gender Balance Ireland (2017-2019): Final Report.* CASTeL, Dublin City University.

Modekurty, S., Fong, J., & Cheng, H. H. (2014, June 15-18). *C-STEM girls computing and robotics leadership camp.* Paper presented at the 121st American Society for Engineering Education Annual Conferences & Exposition, Indianapolis, Indiana. Retrieved 23 March 2020 from https://peer.asee.org/c-stem-girls-computing-and-robotics-leadership-camp.pdf

Murphy, P., & Whitelegg, E. (2006). Girls and physics: Continuing barriers to ‘belonging’. *The Curriculum Journal*, *17*(3), 281-305.

Naizer, G., Hawthorne, M. J., & Henley, T. B. (2014). Narrowing the gender gap: Enduring changes in middle school students' attitude toward math, science and technology. *Journal of STEM Education: Innovations & Research*, *15*(3), 29-34.

National Academies of Sciences, Engineering, and Medicine (2020). *Promising practices for addressing the underrepresentation of women in science, engineering, and medicine: Opening doors.* Washington, DC: The National Academies Press. Retrieved 13 April 2020 from https://doi.org/10.17226/25585

O’Connell, T. (2019). *An investigation of the impact of an industry-focused gender intervention on the self-perceptions and career aspirations of female undergraduate students in the STEM disciplines.* Poster presentation at the 13th biennial conference of the European Science Education Research Association, Bologna, Italy, 26-30 August.

Ogle, J. P., Hyllegard, K. H., Rambo-Hernandez, K., & Park, J. (2017). Building middle school girls' self-efficacy, knowledge, and interest in math and science through the integration of fashion and STEM. *Journal of Family & Consumer Sciences*, *109*(4), 33-40.

Puggarard, K., & Bækgaard, L. (2016). *Handbook on how to make science, technology, engineering and mathematics (STEM) more appealing to girls and young women*. Copenhagen: Nordic Council of Ministers. Retrieved 29 January 2020 from https://norden.diva-portal.org/smash/get/diva2:968893/FULLTEXT01.pdf

Rozek, C. S., Hyde, J. S., Svoboda, R. C., Hulleman, C. S., & Harackiewicz, J. M. (2015). Gender differences in the effects of a utility-value intervention to help parents motivate adolescents in mathematics and science. *Journal of Educational Psychology*, *107*(1), 195-206.

Rule, A. C., Blaine, D. A., Edwards, C. M., & Gordon, M. (2019). Girls explore math careers by making 3D-constructions of diverse women mathematicians' lives. *The Mathematics Enthusiast*, *16*(1), 541-578.

Skills Development Scotland. (2018). *Review of Improving Gender Balance Scotland*. https://www.skillsdevelopmentscotland.co.uk/media/44705/review-of-improving-gender-balance-2018.pdf

Souchal, C., Toczek, M. C., Darnon, C., Smeding, A., Butera, F., & Martinot, D. (2014). Assessing does not mean threatening: The purpose of assessment as a key determinant of girls' and boys' performance in a science class. *British Journal of Educational Psychology*, *84*(1), 125-136.

Stoeger, H., Debatin, T., Heilemann, M., & Ziegler, A. (2019). Online mentoring for talented girls in STEM: The role of relationship quality and changes in learning environments in explaining mentoring success. *New Directions for Child and Adolescent Development*, *168*, 75-99.

Sullivan, A., & Bers, M. U. (2013). Gender differences in kindergarteners' robotics and programming achievement. *International Journal of Technology and Design Education*, *23*(3), 691-702.

The Scottish Government (2017). *Science technology engineering mathematics: Education and training strategy for Scotland*. Edinburgh: The Scottish Government. Retrieved 29 January 2020 from https://www.gov.scot/binaries/content/documents/govscot/publications/strategy-plan/2017/10/science-technology-engineering-mathematics-education-training-strategy-scotland/documents/00526536-pdf/00526536-pdf/govscot%3Adocument/00526536.pdf

United Nations Educational, Scientific and Cultural Organization [UNESCO] (2017). *Cracking the code: Girls' and women's education in science, technology, engineering and mathematics (STEM).* Paris: UNESCO. Retrieved 29 January 2020 from https://unesdoc. unesco.org/ark:/48223/pf0000253479

Ward R. B., Miller J. L. Sienkiewicz, F., & Antonucci, P. (2012). ITEAMS: Increasing the self-identification for girls and underserved youth in pursuing STEM careers. *Journal of Systemics, Cybernetics and Informatics*, *10(*1), 95-99.

Weavers, L. K., Bautista, D. T., Williams, M. E., Moses, M. D., Marron, C. A., & La Rue, G. P. (2011). Assessing an engineering day camp for middle-school girls.

Journal of Professional Issues in Engineering Education and Practice, *137*(3), 127-134.

Zagami, J., Boden, M., Keane, T., Moreton, B., & Schulz, K. (2015). Girls and computing: Female participation in computing in schools. *Australian Educational Computing*, *30*(2). Retrieved 23 March 2020 from http://journal.acce.edu.au/index.php/AEC/article/view/79

Appendix 1: Literature Search Strategies

Table D

Search Strategy and Outputs: Electronic Databases

Database and Search Strategy	Source and Outputs
Scopus	
stem or stm or numerate disciplines or science or technology or math or engineering or physics or chemistry	Abstract
AND	
early years education or school	Abstract
AND	
girl or woman or women or gender	Abstract
Publication Year >2009	
Language=English	
Number of articles	***58***
Web of Science	
stem or stm or numerate disciplines or science or technology or math or engineering or physics or chemistry	Title
AND	
early years education or school	Topic
AND	
girl or woman or women or gender	Title
Publication Year >2009	
Language=English	
Number of articles	***643***
ERIC (ProQuest)	
stem or stm or numerate disciplines or science or technology or math or engineering or physics or chemistry	Title
AND	
early years education or school	Abstract
AND	
girl or woman or women or gender	Title
Publication Year >2009	
Language=English	
Number of articles	***314***

Table D (cont.)

Search Strategy and Outputs: Electronic Databases

Database and Search Strategy	Source and Outputs
EBSCO	
stem or science or technology or engineering or mathematics or math	Title
AND	
girl or girls or female or females or woman or women	Title
NOT	
undergraduate or college or university or higher education	Title
AND	
stem or science or technology or engineering or mathematics or math	Abstract
AND	
girl or girls or female or females or woman or women	Abstract
NOT	
undergraduate or college or university or higher education	Abstract
Publication Year >2009	
Language=English	
Number of articles	***398***
Google Scholar	
stem or science or technology or engineering or mathematics or math	Title
AND	
girl or girls or female or females or woman or women	Title
NOT	
teacher or teachers or teacher's or teachers or undergraduate or college or university or "higher education"	Title
Publication Year >2009	
Language=English	
Number of articles	***258***
Grey Literature (ProQuest Dissertations & Theses)	
stem or science or technology or engineering or mathematics or math	Title
AND	
girl or girls or female or females or woman or women	Title
NOT	
undergraduate or college or university or "higher education"	Title
Publication Year >2014	
Language=English	
Number of articles	*44*

Table D (cont.)

Search Strategy and Outputs: Electronic Databases

Database and Search Strategy	Source and Outputs
OPEN GREY stem or stm or numerate disciplines or science or technology or math or engineering or physics or chemistry	Document
AND	
early years education or school	Document
AND	
girl or woman or women or gender	Document
Publication Year >2009	
Language=English	
Number of articles	***19***

Table E

Search Strategy: Advanced Google for Grey Literature

Search Number	All of these words	Any of these words	Terms appearing
1	Stem Gender Early Years Education		anywhere in the page
2	Stem Gender School		anywhere in the page
3	Stem Gender Government Ireland		anywhere in the page
4	Stem Gender Government	United Kingdom Scotland Wales England	anywhere in the page
5	Stem Gender Government Scotland		anywhere in the page
6	Stem Gender Government United States		anywhere in the page
7	Stem Gender Government Canada		anywhere in the page
8	Stem Gender Government Australia		anywhere in the page
9	Stem Gender Government New Zealand		anywhere in the page
10	Stem Gender Government	Norway Sweden Finland Denmark	anywhere in the page
11	Stem Gender EU		anywhere in the page
12	Stem Gender UNESCO		anywhere in the page
13	Stem Gender OECD		anywhere in the page
14	Stem Gender Higher Education Authority		anywhere in the page

Table E (cont.)

Search Strategy: Advanced Google for Grey Literature

Search Number	All of these words	Any of these words	Terms appearing
15	Stem Gender National Council for Curriculum and Assessment		anywhere in the page
16	Stem Gender Irish Research Council		anywhere in the page
17	Stem Gender Science Foundation Ireland		anywhere in the page
18	Stem Gender Discover Science and Engineering		anywhere in the page
19	Stem Gender Expert Group on Future Skills Needs		anywhere in the page
20	Stem Gender State Examinations Commission		anywhere in the page
21	Stem Gender Teaching Council of Ireland		anywhere in the page
22	Stem Gender Central Statistics Office		anywhere in the page
23	Stem Gender The Further Education and Training Authority		anywhere in the page
24	Stem Gender Royal Dublin Society		anywhere in the page
25	Stem Gender Royal Irish Academy		anywhere in the page
26	Stem Gender Institute of Physics		anywhere in the page
27	Stem Gender Institute of Mathematics and its Applications		anywhere in the page
28	Stem Gender Irish Mathematical Society		anywhere in the page
29	Stem Gender Institute of Chemistry of Ireland		anywhere in the page
30	Stem Gender Institute of Biology of Ireland		anywhere in the page
31	Stem Gender Engineers Ireland		anywhere in the page
32	Stem Gender IBEC		anywhere in the page
33	Stem Gender Intel		anywhere in the page
34	Stem Gender Microsoft		anywhere in the page
35	Stem Gender IBM		anywhere in the page
36	Stem Gender Johnson & Johnson		anywhere in the page
37	Stem Gender Google		anywhere in the page

Table F

Macro Code for Carrying out Automatised Classification of Literature by Discipline

```
IF(cell="GreyLit","STEM",IF(ISNUMBER(SEARCH("Math",cell))=TRUE,"Math",IF(ISNUMB
ER(SEARCH("Science",cell))=TRUE,"Science",IF(ISNUMBER(SEARCH("Physics",cell))=
TRUE,"Science",IF(ISNUMBER(SEARCH("Chemistry",cell))=TRUE,"Science",IF(ISNUMB
ER(SEARCH("Engine",cell))=TRUE,"Engineering and
Technology",IF(ISNUMBER(SEARCH("Tech",cell))=TRUE,"Engineering and
Technology",IF(ISNUMBER(SEARCH("Stem",cell))=TRUE,"STEM","MUST ASSIGN
DISCIPLINE"))))))))
```

Table G

Additional Early Childhood Search Strategy and Outputs: Electronic Databases

Database and Search Strategy	Source and Outputs
Scopus	
stem or stm or numerate disciplines or science or technology or math or engineering or physics or chemistry	Abstract
AND	
kindergarten	Abstract
AND	
girl or woman or women or gender	Abstract
Publication Year >2009	
Language=English	
Number of articles	***8***
ERIC (ProQuest)	
stem or stm or numerate disciplines or science or technology or math or engineering or physics or chemistry	Title
AND	
kindergarten	Abstract
AND	
girl or woman or women or gender	Title
Publication Year >2009	
Language=English	
Number of articles	***7***

Appendix 2: Matrix of Barriers and Interventions

Influence	**Career counselling / information**	**Mentoring**	**Role models**	**Parental engagement with children or schools**	**Teacher-student interaction/language**	**Relevant / innovative / inquiry-based / developmental curriculum**	**Mastery-oriented assessment**	**School culture**	**Out of school programs, summer camps, coding clubs**	**Build science capital**	**Challenge dominant representations of science**
1. Learner **1.1 Language and spatial skills**					Klibanoff et al. (2006) mathematics / early childhood						
1.2 Self-efficacy, self-perception, stereotypes, STEM identities	Falco & Summers (2019) STEM Archer et al. (2020) science		Bagès et al. (2016) maths achievement Lewis et al. (2010) physics belonging Ivey & Palazolo (2011) engineering		Skills Development Scotland (2018) physicsa McLaughlin et al. (2020) physics Lewis et al. (2010) physics belonging Baker (2103) science	Douglas et al. (2014) engineering / early primary Lewis et al. (2010) physics belonging Hazari et al. (2010) physics identity		Skills Development Scotland (2018) physics McLaughlin et al. (2020) physics	Johnson & Johnson WiSTEM2D Ivey & Palazolo (2011) engineering Weavers et al. (2011) engineering	Archer et al. (2020) science	
1.3 Interest, engagement, motivation, enjoyment	Rozek et al. (2015) mathematics & science utility / careers	Stoeger et al. (2019) STEM Modekurty et al. (2014) computer science	Zagami et al. (2015) computer science Modekurty et al. (2014) computer science	Rozek et al. (2015) mathematics & science utility / careers Gunderson et al. (2018) maths/praise Zagami et al. (2015) computer science	Blackwell et al. (2007) mathematics attributions/ incremental theory	Zagami et al. (2015) computer science			Ward et al. (2012) STEM Zagami et al. (2015) computer science Modekurty et al. (2014) computer science	Archer et al. (2020) science	

Influence	Career counselling / information	Mentoring	Role models	Parental engagement with children or schools	Teacher-student interaction/language	Relevant / innovative / inquiry-based / developmental curriculum	Mastery-oriented assessment	School culture	Out of school programs, summer camps, coding clubs	Build science capital	Challenge dominant representations of science
2. Family **2.1 Family**	Rozek et al. (2015) mathematics & science utility / careers			Rozek et al. (2015) mathematics & science utility / careers Zagami et al. (2015) computer science Gunderson et al. (2018) maths/praise						Archer et al. (2020) science	
3. School **3.1 Curriculum and assessment**					Baker (2103) science	Sullivan & Bers (2012) computer science / robotics / early childhood Douglas et al. (2014) engineering / early primary Zagami et al. (2015) computer science	Souchal et al. (2014) science	LaForce et al.(2016) STEM			
3.2 Mentorship and role models		Stoeger et al. (2019) STEM	Baker (2013) science			Baker (2013) science			Johnson & Johnson WiSTEM2D	Stoeger et al. (2019) STEM	
3.3 Teachers					Klibanoff et al. (2006) mathematics / early childhood Skills Development Scotland (2018) physics McLaughlin et al. (2020) physics Eliasson et al. (2017) science / questioning			LaForce et al.(2016) STEM			Lewis et atl. (2016) physics belonging

Influence	Career counselling / information	Mentoring	Role models	Parental engagement with children or schools	Teacher-student interaction/language	Relevant / innovative / inquiry-based / developmental curriculum	Mastery-oriented assessment	School culture	Out of school programs, summer camps, coding clubs	Build science capital	Challenge dominant representations of science
4. Society (including industry and community groups) **4.1 Society, legislation, policies**											Archer et al. (2020 science
4.2 Informal learning supported by business, industry, university, community, informal learning			Johnson & Johnson WiSTEM2D Ivey & Palazolo (2011) engineering Weavers et al. (2011) engineering						Johnson & Johnson WiSTEM2D Ivey & Palazolo (2011) engineering Weavers et al. (2011) engineering Modekurty et al. (2014) computer science Archer et al. (2020) science	Archer et al. (2020) science	