MODESTUM EURASIA Journal of Mathematics, Science and Technology Education, 2025, 21(12), em2747
ISSN:1305-8223 (online)
OPEN ACCESS Research Paper https://doi.org/10.29333/ejmste/17493

Current obstacles in global STEM education and a possible practical solution to overcome these

Tamás Kovács [1*], Gavin Hanjra [1]

[1] A&J School, London, UK

Received 18 August 2025 ▪ Accepted 22 October 2025

Abstract
Science, technology, engineering and mathematics (STEM) play a crucial role in human society. While regions differ in their approaches, technological modernisation is a common driving force worldwide. For instance, while mathematics has been a cornerstone of education since ancient times, valued for its role in the development of civilization, 'math anxiety' persists into the 21st century. Furthermore, participation and performance in STEM subjects continues to see gendered disparity. This is a problem as this is rooted in sociological misconceptions and potential discrimination. In this work, we review a range of STEM education strategies currently being implemented in schools (in primary and secondary), based on available literature sources from the last decade. Drawing on the empirical findings from the review and our own practice-based analysis, related to learning anxiety around mathematics and gender gap, we lay a foundation for a specific STEM learning model designed to encourage children's innate development, curiosity, intrinsic motivation and sustained engagement in STEM learning. This evidence-based conceptual model is based on scaffolded "learning-by-playing" and integrated art and playful activities into early years' mathematics and science education that could give the foundation for enhanced interest and narrowed gender gap in mathematics rich science subjects.

Keywords: STEM education, obstacles, gender gap, confidence, motivation

INTRODUCTION

Technological development is fuelled by several forces: environmental challenges; national and international economic competition; scientific breakthroughs, and societal demand. As society becomes increasingly reliant on technology–bringing both opportunity and challenge–and international competition to excel into the technological future becomes fierce, education systems globally are increasingly prioritising STEM.

It is important to have a deeper understanding of technological and scientific details, and this is related to effective education of science (S), technology (T), and engineering (E). Therefore, it is not surprising that in more places more weight is placed on effective education. However, it is also clear that the common factor in the three elements, namely mathematics (M), is not following the pattern. Mathematics is thought to be difficult, and it is quite often not embarrassing not to achieve well in it. STE education is not complete without mathematics and STEM needs to be considered together. The last letter in the acronym acts as a glue as this holds the other parts strongly together. Mathematics is the language of all the other elements.

In all areas of the world in primary school classrooms children are introduced into mathematics at early stages and it is usually started with timetables and counting. Therefore, the very first concept of the subject is far from exciting, and this builds strongly into children's memories. It often lacks a connection between real life scenarios and numbers. On the other hand, primary science is usually related to facts (in the British education system there is not even named science lessons in primary schools).

In this study we provide a review that is considering the British education system applied in England and in the Middle East and the post-communist Eastern European model. This work aimed to see if education systems in regions with different historical backgrounds,

✉ takovacs@gmail.com **(*Correspondence)** ✉ gavinsinghhanjra@gmail.com

Contribution to the literature

- This paper will provide a significant contribution to the international community of STEM teachers as we provide useful and comprehensive discussion of applied STEM education strategies.
- This paper provides a unique perspective on how to implement interesting and inspiring elements into STEM education to boost students' interests and achievements via a global synthesis.
- This paper offers a new practical learning model.

where a wide range of data and background information are available via literature sources and our own practice, could apply similar learning methodologies. The aim of the study is to provide a model, based on collaboration and constructivist theory based "learning-by-playing", that can be successfully applied in any society and could lay the foundation for "making STEM great and engaging!" We will provide a comprehensive analysis of the advantages and disadvantages of the current education systems and based on our findings and our experimental tests we will provide a universal set of ideas of how to make effective steps to build an effective STEM education that would be advantageous for societies. This study provides a combination of literature review, practice-based field research and analysis and evaluation of all these and the suggestions are based on all these inputs.

BACKGROUND AND REVIEW: STEM EDUCATION IN DIFFERENT COUNTRIES

Theoretical Frameworks for Effective STEM Education

Bolton and Delderfield (2018) underlines all the aspects of the effectiveness of reflective practice in education. She builds on the idea of 'analysis of experience' and she clearly identifies the effectiveness and usefulness of reflective practice not only in the field of education but also in politics and in the whole society. Borrero et al. (2016) and Felicia (2023) also underline the necessity of professional reflection which is an essential part of the teaching profession. Gibbs' (1988) reflective cycle is a brilliant description of the ideally effective teaching practice. This work provides useful details of all the stages of the cycle and facilitates self-development by identifying strengths and targets. This model enables the practitioner to identify target points and to reflect on them and it also helps to focus on how the effectiveness of strategies could be improved even more. Conclusions are made from the qualitative (and possible quantitative) analysis which can be implemented in future planning. In practice, this can happen via recorded lessons, peer-observation or student surveys. All this is based on reflective practice that uses Gibbs' (1988) model. Our interview-based data, that was conducted with 50 teachers in England, Saudi Arabia, and Hungary, suggests that student surveys turned out to be the most effective way for self-reflection. 30 out of the 50 interviewed teachers carried our student surveys and 28 of them found it very valuable: the most common issue they identified was lack of attention to all students in a practical session. 5 of these teachers did lesson recording and that helped them further understand how they could increase the effectiveness of practical sessions by correct grouping and seating plans of students. They also realised that a short, assessed knowledge test before practical's could eliminate behaviour issues.

Constructivism provides a connection between learning and knowledge (Fosnot, 2005) and can be applied as a generalized pedagogical device. In a critical paper (Matthews, 2012) the author claims that constructivism generally had dominance in worldwide education until the last decades of the 20th century. He clearly points out the influence of constructivism in different parts of the world and concludes that it is still the official learning theory in some countries (Thailand, Greece, and India). Its influence on science education was studied by Bell (1991) who considers it as "view of science". In radical constructivism (Quale, 2008) the author points out that the knowledge is gained through the process of learning therefore knowledge is defined as the final individual product of learning. In science it is even more crucial to learn through observation as observation is the only way to get knowledge from the world that science deals with. This element is clearly missing or not considered with appropriate weight in general. Normal stages of child development do reflect observation phases and, how science works and therefore it is important to focus on this key element before we go into details with science education.

A key aspect of early STEM education is introducing calculation strategies grounded in a strong understanding of mathematical concepts. At this stage, language development, numeracy and social skills form the foundation of learning. It is clear that there are obstacles in global STEM education and two of the key factors are gender balance and subject anxiety, especially in maths (Muhammad et al., 2024). Women still represent only 35% of higher education students (Durrani & Kataeva, 2025). It is important for schools to demonstrate women's contribution to global STEM by pointing out the role of female managers in STEM related sectors and to underline the influence of famous female scientists.

Since the COVID-19 pandemic there has been a trend to shift towards digital technologies. Based on interviews with company directors in England, project-based learning and STEM related apprenticeships have become more important as during the lockdown's companies realized the need for STEM related skilled professionals at different levels. These factors, together with competitive salaries, can make STEM more attractive to young generations. However, it is still too early to draw a definite conclusion.

On the other hand, maths anxiety is another serious and more complex problem. Megreya et al. (2025) pointed out that math anxiety on the global scale is rooted in strong psychological and cultural misconceptions and misbeliefs and partly directly related to the not narrowing gender gap. The authors suggested that psychological interventions for high math-anxious female students could potentially improve female STEM participation not only in education but in relevant jobs, too.

Case Studies: British System in the Middle East

Over the past four decades, Middle East countries such as Saudi Arabia have built strong ties with Western nations and successfully implemented the British curriculum and exam systems in many schools (OECD, 2020). Numerous British schools operate across the Gulf region, often staffed by qualified teachers from the United Kingdom (UK) recruited with competitive terms.

In many developed countries, there has been a decline in students taking up an interest or a career in STEM, leading to fewer qualified STEM teachers and professionals, despite a rise in STEM research. A comparative study by Muhammad et al. (2022) examined STEM education in the USA, UK, Japan, and Australia. This study emphasised the global importance of STEM and the efforts made to boost student interest and enrolment. The study found the following differing national approaches: in the USA, community elite involvement is key; the UK focuses on curriculum support and teacher training; Australia faces a shortage of scientists and engineers, addressed through targeted policies; Japan has effectively increased student interest and participation in STEM. We believe that these insights can guide educators and policymakers in enhancing their STEM programmes.

Middle East: Saudi Arabia and the wider region

The Gulf countries have made significant investments in STEM education as part of their strategy to move towards knowledge-based economies. However, we can see that progress and performance vary across the region (BouJaoude, 2020; Karafyllis, 2015; Kayan-Fadlelmula et al., 2022).

Policy context: Saudi Arabia, under vision 2030, is focusing on developing human capital and reducing its reliance on oil (Baikalizadeh et al., 2025; Kayan-Fadlelmula et al., 2022). This has led to major reforms in STEM education, including the integration of AI, robotics, and space exploration into school curricula, as well as the establishment of dedicated STEM schools.

Current challenges: In the Saudi education system, science is compulsory to all students until the 10th grade. From then they can choose a science stream to continue studying it (OECD, 2020). Teachers are usually instructed on their respective subjects separately, and do not usually collaborate when planning lessons resulting in very little cross disciplinary content. This does not promote a culture for STEM education since parallel, cross-disciplinary and infusion interdisciplinary curriculum doesn't exist. While practical lessons in science labs do take place, they are often ignored or deemed unnecessary to the curriculum. In many cases maths and science are taught through a discipline-based approach instead of with connections to real life situations or projects, however for this to change, the teachers can provide information about how integrated STEM education could be introduced.

Gender balance is an ongoing issue in STEM subjects not only in Saudi Arabia but in the region in general. However, in Qatar (also pursuing vision 2030) women make up 70% of STEM school graduates and 51.6% of university engineering students (Özoral, 2022).

A general issue in the Gulf Region is the lack of enthusiasm of students towards STEM and the lack of motivated STEM teachers. Therefore, it is common to import educated and vetted STEM teachers from abroad, mainly from the UK.

Empirical evidence: Teachers on board must believe in innovative teaching strategies and have deep content knowledge, since claims have arisen of science and mathematics teachers with limited practical experience, which a study has specified as 30% of middle school science teachers lack in field training (El-Deghaidy & Mansour, 2015).

The two inquiry questions are: "What are science teachers' perceptions of STEM education?" and "What are the factors that facilitate and hinder STEM education practices?" Results were gathered though focus group interviews from 21 middle school science teachers in Riyadh. The authors aimed for the teachers to implement lesson plans, reflective papers, and interview protocols because of the study, however only 2 teachers did. From results it was found that all the teachers felt underprepared to implement STEM practices in their teaching, and believed Technology was very important for this. This demonstrates a lack of cross-disciplinary integration. STEM integration was viewed as useful for developing students' 21st century skills and inspiring students by linking their education to real life situations.

Implications and recommendations: The interviewed 5 teachers based in Riyadh mentioned that professional development programs where science, maths, engineering and technology teachers collaborate about lesson planning would be essential for STEM education being promoted in schools, and that long term partnerships should be formed. These partnerships allow for more meaningful projects to happen with students involved. The culture of each school also affected the integration of STEM, with constant dialogue between teachers, students and admin being found necessary for the best outcomes.

In general, the region shows a strong commitment to STEM education development, with each country offering unique advantages depending on individual student needs and career aspirations. The UAE currently provides the most comprehensive STEM education environment, while other countries offer emerging opportunities with significant government backing and investment. The energy-based industries provide great opportunity for research and industry supported STEM programmes, but these are yet to be further implemented.

It is recommended to facilitate collaboration between education and industry by formal contracts and enhanced outreach activities. It is more beneficial to start to implement this policy at early stages (primary school) via well-planned industrial visits where children would be able to observe real life STEM in action and they might be even given the opportunity to do some hand-on activities on site, too.

Global Comparative Studies: England and Eastern Europe (Hungary)

Western Europe: England

In England the typical education of children starts at the age of 4 where they enter Foundation year of primary education. Students enter secondary education at the age of 11 and they finish at the age of 16. Between age 16 and 18 the transitional period (post 16, A-level) involves preparation for higher education and teaching and learning is focussed mostly on the selected career path related subjects.

Early childhood and primary STEM education: At the age of 3 children have the opportunity to enter nursery school or pre-school. In these settings children have playful sessions where they develop social, emotional and basic literacy and numeracy skills. The activities include lots of art and music. These are basic elements of personal and social development of each child. Educators regularly monitor the children's progress, and they keep records of them that are shared with parents. Children often learn best through experiences that feel like play, without realising they are learning. This is especially true in STEM activities and language development.

In primary schools, learning becomes a bit more structured, with a strong focus on literacy, phonics, and numeracy, especially times tables and counting. Because of this, the introduction to numbers can sometimes feel to the child like memorising facts, which can lead to boredom. But with the help of technology, maths and other STEM subjects can become much more engaging. Games and visual tools can turn learning into something exciting and interactive.

Secondary and post-16 STEM education: More and more secondary schools are realising that combining hands-on activities with theory really boosts STEM learning. That's why many are now using integrated STEM approaches and linking science topics with practical design and technology projects (Larkin & Lowrie, 2023). This helps children see how what they're learning applies in real life and also builds their maths and engineering skills. The success of these projects often comes down to how well they're designed and the positive relationships between teachers and students. A successful foundation could enhance STEM teaching and learning in secondary education, too. Without this the general strategies including science week and STEM projects will not lead to success.

Teacher preparedness and systematic challenges: The motivation should come from not only from centrally determined and constructed plans but from individual educators, too. However, the fact is that teacher preparedness is still a critical challenge in England's STEM education system. The rapid technological development and additional needs of adaptations of methodologies combined with a bureaucratic quality assurance system makes it challenging to recruit talented and passionate STEM professionals. This is still the case, despite teacher support initiatives in place like teacher training bursaries, scholarships, extra funding for professional development. Typically, the teacher salary remains low, compared to some other people centred professions like medicine. The unnecessary pressure from school leaders and quality assurers make teachers reluctant and their typical mentality is to survive from half term to half term break. The key point of school training sessions is often related to inspections and data. Although there are exceptions, the typical approach for school leaders is to show good data to get good inspection results. And this pushing approach penetrates down to individual departments. As a consequence of all these, England faces significant shortages of qualified and motivated STEM teachers, particularly in physics and mathematics (Smith & Gorard, 2011).

Although England demonstrates international leadership in educational reform and official student outcomes, regional variations highlight the need for continued focus on equity and quality across all parts of the UK. The country's early adoption of computing education, strong performance in international assessments, and growing student interest in STEM subjects provide a solid foundation for future development. However, addressing teacher shortages,

Table 1. Growth of mathematics and physics A-level entries from 2023 to 2024 (FE News, 2024)

Subject	2024 entries	Growth from 2023
Mathematics	107,427	+10.9%
Further mathematics	18,08	+19.9%
Physics	43,114	+12.3%

supporting post-pandemic recovery, and maintaining competitiveness with global leaders remain critical priorities for UK STEM education policy and practice.

Recent trends and gender balance: Although the recent 2024 A-level STEM data show some promising signs of unprecedented growth in STEM subject uptake (see **Table 1**), signalling strong student interest in science and mathematics pathways (Engineering UK, 2024; Thompson, 2024), it is not clear whether the trend continues with the same trajectory.

Based on the data, mathematics became the first A-level subject to exceed 100,000 entries (Thompson, 2024) and further mathematics showed the highest percentage growth of any A-level subject (FE News, 2024), despite the fact that further mathematics is far the hardest A-level subject. Furthermore, female participation in physics increased remarkably: by 23.3%. Despite this promising pattern, significant gender disparities persist in STEM subjects (Engineering UK, 2024; Smith & White, 2025). Core STEM subjects accounted for 30.3% of all female A-level entries compared to 47.7% for male entries, indicating ongoing challenges in gender balance (Smith & White, 2025).

The percentage of female representation in core STEM A-level subjects in 2024 is represented by these figures (Engineering UK, 2024):

(1) biology: majority female participation,

(2) chemistry: 50% female,

(3) mathematics: 37% female, and

(4) physics: 23% female.

If student-centred constructivist approach is embedded into the learning framework from early stages it could develop into a less guided and more open-ended learning trajectory where students would be encouraged by the individual pillars of their understanding and self-scaffolding in curiosity will enhance their STEM learning (Taber, 2017). It is important that children have different perspectives on science related contents and phenomena when it is based on prior knowledge compared to their own discovery-based interpretations. When they find a gap between the two constructions they will fit the contexts to their experiences (Driver, 1989). Primary and secondary school students clearly distinguish between "official" scientific explanations and their "real world" observations and explanations. This sometimes could lead to cognitive conflict, and this could trigger subject anxiety. The positive trend shown in **Table 1** could be related to the fact that during the COVID-19 pandemic lockdowns children were isolated and were more reliant on their creativities and experiences. This could have built up their enhanced interest in STEM and related careers.

In face-to-face classroom settings it is important to allow students to observe and to explain the phenomena with their own constructive minds. One important practical element for it could be to strengthen connections between education and STEM related industries that remain critical for STEM education success (Murphy, 2020). The UK's approach through organizations like the RAF Youth STEM program demonstrates effective models for broader application (Robson et al., 2025; Rose & Joyce, 2018) but the model is not generally applied.

Eastern Europe: Hungary

Historical context and system structure: In the communist decades of Eastern Europe, it was typical to put the political system into focus. In general, especially in humanities and social sciences, creative learning was not prioritized; instead teaching and learning focussed on memorization and strict structures. After the democratic transition in 1990 the education system kept the main structure. For example, in humanity lessons students were expected to memorize full texts. The system was designed for short term memorization rather than long term creativity and logic.

Primary education structures vary considerably across Eastern European nations, reflecting different educational philosophies and historical developments (Kozma & Polonyi, 2004; Silova, 2009). In Hungary, primary education encompasses four years (grades 1-4), followed by lower secondary education in grades 5-8 (Balázsi & Ostorics, 2020). This differs from neighbouring countries: Poland operates a six-year primary system, the Czech Republic implements five years, while Slovakia mirrors Hungary's four-year structure (Munkácsy & Scharle, 2021).

Curriculum and pedagogy in STEM: The curriculum organization shows consistency in science education approaches across the region (Kácovský et al., 2022). Most countries begin with integrated science subjects in primary years, gradually transitioning to separate disciplines (biology, chemistry, and physics) in lower secondary education. This pedagogical approach recognizes young learners' developmental needs while building toward more specialized scientific knowledge (Dyachenko et al., 2024).

Secondary education across Eastern Europe typically divides into lower and upper phases, with varying structures designed to accommodate different academic pathways (Kogan et al., 2012). Hungary's system includes traditional grammar schools for academically gifted students, secondary vocational schools for intermediate learners, and technical schools preparing

Table 2. Growth of mathematics and physics matura examination entries from 2023 to 2024

Subject	2024 entries	Growth from 2023
Mathematics	64,047	-9.9% (2023: 70,394)
Advanced mathematics	6,616	45.8% (2023: 4,537)
Physics	1,378	No data
Advanced physics	1,809	No data

students for vocational education (Bacsa-Bán, 2022). This selective approach, common throughout the region, has drawn attention for its potential impact on educational equity (Connelly, 2010).

The flexibility within these systems enables students from vocational backgrounds to access higher education through additional programs (Bacsa-Bán, 2022). However, research indicates that Eastern European countries tend toward more academically selective upper secondary enrolment compared to OECD standards (Connelly, 2010).

Assessment and student participation: Hungary maintains a distinguished reputation in mathematics education, rooted in a strong cultural tradition that emerged in the early 20th century. The Hungarian pedagogical approach emphasizes heuristic methods and problem-solving, with focusing on mathematical creativity and deep conceptual understanding (Szakács, 2018). This methodology, developed through decades of refinement, emphasizes conceptual connections over rote memorization.

Secondary school students are assessed in the matura examination that are divided into ordinary and advanced exams. The number of students who took advanced exams are usually significantly lower in STEM subjects (**Table 2**).

From the data there is clear evidence that significantly more students took advanced mathematics, but it is not clear whether this is just a one-off, or the trend will continue. However, physics is a very unpopular optional subject. And there is a correlation between the low number of specialist teachers and the number of students.

Considering the serious shortages in physics and maths teachers (Collinson, 2025), the remarkable growth in advanced mathematics entry is clearly very noticeable. Based on personal communications with active maths teachers who work in high schools in Budapest, Miskolc and Debrecen–who asked to be anonymous–, after the COVID-19 pandemic students started to realize more that only advanced level mathematics can give them the necessary tool to enter into engineering professions. However, due to the lack of data, from the current one-year data we cannot definitely conclude a positive upward trend yet.

Strengths and weaknesses: The Hungarian system's effectiveness is evidenced by its consistent performance in international assessments. In TIMSS evaluations, Hungarian 13-14-year-old pupils rank among the world's best in mathematics and sciences (Bacsa-Bán, 2022). The pedagogical approach involves sequenced problems that create coherence and focus, with group-wide discussions of problem-solving approaches serving as a hallmark of Hungarian mathematics instruction (Szakács, 2018). In science education this approach is not replicated. Based on our communication with STEM professionals in Budapest and Debrecen who requested to be anonymous, the main reason for it is clearly the lack of professionals and lack of funding in STEM learning. As science subjects require more investment due to essential practical elements, the funding restrictions on universities make it hard for them to attract talented students who could be good future educators.

Challenges and future directions: In Hungary STEM education still has some unnecessarily overstructured elements that include rigid elements of short-term memorization. But this is not the major factor for the low number of STEM passionate students. The exam results are typically good for STEM subjects but the number of students who take the optional science subjects is concerningly low. It is not because students would not be interested in sciences, but they see that the career prospect in the region is really poor plus the very low number of specialist teachers makes it difficult to energise the students in STEM.

Although the STEM teacher shortage is a typical trend in Europe including Eastern Europe (Pokropek, 2024), that is due to large workload and often lack of respect towards the profession together with low salary, the situation is even more acute in Hungary. The shortage of STEM specialist teachers in Hungary is critical: there is a shortage of at least 17,000 STEM teachers (Kertesz & Rutai, 2023); the most severe is the shortage of 3,500 physics teachers (Collinson, 2025). Based on our communication with professionals who requested to be anonymous and their unpublished data, about 1/5th of the schools are facing teacher shortages in chemistry and biology, too and since 2023 the biggest demand has become for maths and physics teachers. Due to government restrictions on publications of official figures, exact numbers are not known. It is important to address the issue and to introduce direct policies to deal with the issues. From a professional point of view a good starting point would be to separate the administration of the education sector from the Ministry of Internal Affairs led by a former chief police officer as the minister and to delegate it under a separate Ministry of Education that should overview the education sector and should start consultations with headteachers and teacher training providers. Without a quick intervention more and more teachers keep leaving the profession and it will become even more difficult to repair the sector's reputation.

In this section the effectiveness and educational approaches in different countries have been discussed. As a comparison, it is important to note that in developed East Asian countries like Singapore or Korea, the emerging pedagogical solutions strongly rely on technology-enhanced personalized learning - and as examples show these can offer positive pathways to enhance the access to high quality STEM education (Abuhanasein et al., 2025). Singapore's systematic and modernising STEM education reform is an outstanding example of great pedagogical and forward-thinking philosophy. STEM subject specialists are entitled to intense and meaningful training in both academic content and pedagogical approaches, and the ongoing professional development guarantees that the educators stay motivated and up to date with best practices. This approach and policy also maintain high standards for teacher recruitment and provide competitive compensation that attracts talented individuals to the profession (Singapore Maths, 2025).

DISCUSSION

In early years children's conceptions develop rapidly based on their experiences. A child can easily learn how their behaviours are related to sociologically tolerated concepts and their positive or negative personalities. Small children learn from repeated patterns, and they shape their personalities. We have seen examples of ethnic minority children in Hungary where children told, "I am bad", that was purely based on the repeated anger-based comments from parents like "you are bad". Sadly, these children will be determined to be progressing slowly, and a negative mindset will nominate their learning process and their education destination.

On the other hand, we have seen very confident children in different countries including Hungary, the UK or Australia where children progressed rapidly based on the confidence learnt from lots of parental attention and support.

Educators have a crucial role in shaping the society by helping children to develop a healthy mindset and to allow them to fulfil the best of their potential.

Alongside developing effective communication (language development including spelling or writing), mathematics and science are equally important as these areas provide the direct link between individuals and the world around us. Therefore, attention to these areas is equally important to language development.

STEM learning is strongly related to models and creativity that is linked to language and communication, too. Hallström et al. (2023) underline the importance of integrated STEM projects that combine modelling and design. Although design is a crucial part of engineering, it is not restricted only to it. Science based projects and discoveries are strongly linked to basic needs and sociological demands. The idea of model construction is a natural element of child development and therefore, involving construction sets and its combination with imaginative projects could significantly boost children's interest in STEM. The authors suggest that minimising uncertainty and maximising clarity and authenticity in STEP education are important to get the learning audience effectively involved. The international Delphi findings discussed by the authors have the potential to integrate STEM classroom-based interventions with teacher development and curriculum design

Gopnik (2012) and Klahrl and Nigam (2004) suggest that science is based on cognitive development that happens in similar stages as the development of science. This recommends that children are really open at early stages, and it can never be early enough to start introducing complex scientific strategies. As Metz (2016) suggests the language was kept at a simplified level to motivate effective learning and therefore, individual development. Experiments were planned to respond to students' understanding on the theoretical foundations to help with the students' learning and development (Moon, 2013).

We tested how the implementation of art in science and mathematics education enhances the learning and its quality in primary classrooms.

Tests in Primary and Secondary Education

One of the tests we did was running a STEAM club for primary aged students in a British school in Riyadh. This included year 3 to year 6 students–the club is called primary STEAM thinkers. Over the course of three months, a total of eleven sessions were held after school where students completed interdisciplinary group projects as an opportunity for hands-on learning about various topics in the STEM collective.

Our goal was to use art, which has been established earlier, as relatable, familiar and enjoyable to these students to provide a bridge to scientific ideas that might be intimidating or difficult to grasp. Each week, students completed a project in groups where they often had to engineer and design something, and they also learnt about scientific concepts explaining aspects of their current projects through the use of simple presentations. The knowledge from these presentations was then in turn put into practice when they would work on their projects, promoting the aforementioned hands-on learning. When projects were completed or the time limit expired, a competition was held with candy as prizes for the most well-performing groups to increase motivation.

The projects completed were as follows:

1. Build a boat: students had to construct boats out of provided materials and see which design can carry the most weight without sinking.
2. Paper planes: students made multiple paper airplane designs and competed to see which ones flew the furthest and why.

Table 3. Perceived enjoyment of different STEM projects across the 8-week period

Project	Perceived enjoyment	Males to females ratio
1	2	7:8
2	4	8:7
3	5	8:7
4	3	2:3
5	5	3:2
6	4	8:7
7	5	7:8
8	4	8:7

3. Egg drop challenge: students made multiple modifications to boiled eggs with materials provided to them to try and prevent them from cracking when dropped from a 6-metre balcony.
4. Lemon battery: students investigated the use of makeshift copper and zinc electrodes with lemons to power LEDs.
5. Baking soda volcanoes: students made papier mâché volcanoes and simulated eruptions using baking soda and vinegar.
6. Stomp rocket launcher: students constructed paper rockets for a rocket launcher made of PVC pipe and a soft drink bottle and competed for which one travelled the furthest and highest.
7. Paint pendulum: students made different designs on paper using a cup dripping paint acting as a pendulum.
8. Popsicle stick bridge: students constructed different designs for bridges spanning 15 cm out of popsicle sticks and glue and competed to see which design could carry the most weight before breaking. Art was integrated into all these projects through decoration, or providing a platform for the competitions, such as the papier mâché volcanoes.

During these activities we quantified the outcome of the individual sessions.

The perceived enjoyment of each project (how much the students seemed to be enjoying the project on a scale of 1 to 5, where 5 is the highest) and the gender ratio of each session (how many boys and girls attended the session) are shown in **Table 3**.

It is clear that at the beginning students showed a lack of enthusiasm and that was based on their lack of confidence and the significant factor of uncertainty. However, over the course of all the projects, initially reserved students became a lot more confident and willing to participate in activities and even discussions. The students responded well to more structured activities but really enjoyed and expressed themselves during the artistic sections, such as decorating or making new designs for paper aeroplanes or bridges. Two students (who were initially uncertain and shy) out of our class of fifteen were especially strong, and while they won most challenges, they always helped the other students to improve their projects even in competitions.

Table 4. Number of total and male and female responses-1

Score	Number of responses	Male responses	Female responses
1	60	0	60
2	21	0	21
3	79	39	39
4	19	20	0
5	61	61	0

Note. Overall average: 3.00 ± 1.50; Male score: 4.20 ± 0.91; & Female score: 1.80 ± 0.89

Table 5. Number of total and male and female responses-2

	Number of responses	Male responses	Female responses
Yes	138	82	57
No	102	38	64

The sessions started with quick presentations during which they quickly learnt that the best way to explain concepts to them was using analogies and diagrams.

For example, in one lesson, students were not understanding the concept of how electricity worked until we broke it down as trucks (electrons) carrying cargo (charge) to an understocked store (to explain potential difference).

The club was not entirely truthful to its name. While science, technology, engineering, and art were represented fairly, mathematics was, as it often is, neglected. Mathematics is a more abstract area than science and sadly it can be considered to be suitable only for those who have the right mindset.

Noticing this shortcoming and realising it even in our own test, we conducted a survey on 240 year 12 students on mathematics from a range of settings. Below are the questions asked and the results we obtained:

1. How much do you like mathematics on a scale of 1 to 5 where 1 is the lowest?

It is clear from the results that males like maths better than females (**Table 4**). In order to specify the reasoning behind we have shaped a direct, career related question in the survey:

2. Do you think or plan to use maths in your future career?

From these results it is clear that males tend to choose a maths related career more likely than females that is again, related to the previous question (**Table 5**).

In order to see the bigger picture and understand the underlying cause we have phrased a direct question on the effect of teachers on the passion of mathematics.

3. How much have your past and present teachers affected your opinions on maths?

It seems that teacher influence appears to be significant with an average score of 3 (**Table 6**).

Table 6. Number of total and male and female responses-3

Score	Number of responses	Male responses	Female responses
1	40	19	21
2	58	21	37
3	82	58	24
4	10	8	2
5	50	14	36

Note. Overall average: 3.00 ± 1.40; male average: 2.80 ± 1.20; female average: 2.50 ± 1.50

However, interesting that among female students the number of highest influence (score 5) appears to be a lot larger than among males. Also, for females the data is a lot more scattered than for males. This result suggests that teachers have enormous responsibility in shaping students' minds and their careers.

It is important to understand why mathematics is an outsider and we carried out further educational tests in secondary settings that were aimed at combining mathematical concepts into science.

One of our other tests was replicating the model example demonstrated in advanced cell biology lessons in Scager et al. (2014). In this test lower secondary school high ability students (age 11-12) were challenged by a higher tier task where they needed to rearrange the general physical formula at least once. When their confidence was evidenced in questioning and written tasks the level was raised to upper secondary level (age 15-16). They were also offered pair discussions where they needed to convince each other about their own scientific ideas. This seemed to be an effective additional factor in motivation (Kuhn, 1997).

Students' progress was monitored regularly in each lesson, and it was concluded that by lesson 3 all of the 11-12-year-old students could implement the calculation strategy in their scientific development. In the electricity topic 6 weeks later, the same students needed to use their knowledge in resistance, current, and voltage. 95% of the students remembered all the steps of the method and they used it consistently correctly throughout the new topic. The remaining 5% was helped mainly by their peers and by the end of the first lesson on the new topic they recalled their knowledge successfully and they demonstrated it in the next lessons, too.

Another test was done in an ecology topic where 11-12-year-old students were allowed to work in groups of 3 and were taken outside to count different types of insects and plants in different environments. The majority of the same students started to show enthusiasm from the early days of their secondary STEM lessons and about ⅓ of them attended regular weekly chess clubs, too. Without any discipline issues, all the students prepared for their practical work and, although their natural excitement caused minor disruptions, they all carried out the practical work accurately. The effective teamwork led them to develop peer-support in the result analysis, too.

All these tests clearly show that regardless of the age of students or educational settings, joy and playfulness remain key elements of successful STEM learning. Even in the animal world animals learn and develop via plays and that makes them adapt to future challenges, while they develop strong social skills.

Our practice-based evidence and interviews with a range of educators in Saudi Arabia, England, and Hungary shows that real life experience that a child considers "magic" will strongly build into their mind. It is highly recommended that in pre-school and early primary education children are shown lots of wonders. Even a super simple activity like cutting a sheet of paper in half and keep repairing it until it becomes practically impossible. Then, at that point the adult can ask: "Why do you think you cannot halve it further?" and "If you were able to decrease the size of your hand could you keep halving it?" Or another interesting simple idea is to show them a compass and make them think about it or even just put a magnet under a table and make an iron object move on the top of the table with it. There are several more possible simple examples that are fully suitable to build curiosity towards STEM in children's minds. The same with mathematics. The adult can ask the simple questions: "How many parents do you have?"–and this question could lead into a conversation that concludes that there are objective and absolute ideas. Geometry is another interesting area for them but interestingly children's minds are set to Euclid geometry from early stages. It would not cause any harm to bring up the question: "What would be the shortest distance between two points on the surface of the sphere?" It is not right to assume that small children cannot think in an abstract way, it is just the opposite: their flying creativity makes them amazing and the best explorers!

Below we will consider all our findings and the literature review and will provide a unique STEM education model that would be suitable to be applied in any setting and cultures.

A Potential Solution for a Successful STEM Education

Based on the review and our experimental study, we recommend the following steps to build a robust and successful STEM education program:

First of all, teachers should be motivated by attractive wages and allowing them to be themselves and enjoy the profession. Therefore, with competitive wages, recruitment to teacher training programmes should focus on picking the right personalities for different subjects. It is correct to test the abilities of candidates in real educational scenarios and to apply Oxbridge-style interviews to test how candidates can deal with unexpected problems and whether they are truly fit for the requirements of resilience, positive mindset, discipline etc.

Once well qualified and passionate professionals dominate education that will start causing an immediate positive change. They will not only know the theory of pedagogy but would be willing to do it in the best interests of their students.

The passion towards STEM should start in the earliest possible stages when communication and socialising skills are still being developed. There is no difference between boys and girls for this. Einstein's curiosity for physics started in his early childhood by observing a compass.

Starting with playful activities in pre-primary and in primary schools both for science and mathematics would provide a great foundation as the children's natural development is being implemented into structural learning. Besides simple ideas mentioned in the previous paragraph, the activities should include art related activities like associating numbers with colours, colours in nature, ordering shapes.

Once the first 2-3 years are fulfilled with joy in STEM it will strongly determine their consciousness towards it and their natural talent and creativity will flourish. And it will also relate to an accelerated development of their language skills as in order to express themselves they need to find a way to communicate.

Also, the very nature of children is that they like competitions. Therefore, arranging groups works in the class will fulfil this requirement. On the other hand, boardgames will add to this and they will stimulate the creativity development in their minds. One great example is chess. It is recommended that in any educational setting there should be chess sets and opportunities for children to quickly learn the rules and play chess.

This structure of spontaneity and facilitated creativity will generate a connection between key scientific and mathematical concepts and easily approachable ideas (colours and shapes) in the children's minds. On the other hand, the children will love education as they will associate education with wonder and excitement. Formal graded assessments are not recommended in primary education. Communication between parents and teachers should happen in person meetings where regular updates are given and via end-of-year reports that summarizes the annual progress of the children.

Once this foundation has been given then in upper primary and secondary education they should build on it. Of course, it might require recreating new sets of curriculums that require more flexibility and keep facilitating creativity. In upper primary years when children have more consciousness of themselves and their abilities they should have career sessions where they are given the opportunity to express them and to start forming paths towards them. It is almost guaranteed that the number of children who will orientate themselves towards STEM will increase massively. As a consequence, selection towards these subjects later in higher education and in jobs will be a lot more selective.

Secondary STEM education should be a natural continuation of the primary phase but with the inclusion of more specific details and more risk-taking including experiments, arranged visits out to nature and to industrial sites. Once the children start having clear interest and orientation in certain subjects it should be further facilitated by visual activities and experiences. The assessment strategy in secondary education could move to the next stage but it is not a right idea to focus the children's mindset on the future exams. Therefore, it is recommended that assessments should be related to measure their natural development via facilitated groupwork, coursework assignments and competitions, rather than end of school exam preparation from day 1. In general societies should move towards the idea of collaboration. In a half term STEM coursework, the students will develop their teamworking, researching and academic writing skills that are fully appropriate for 11-16-year-old ones. Any remaining gender gap could be easily overcome by allowing boys and girls working on the same projects, especially from age 13-14.

11-year-old children are very much capable of understanding the language of mathematics and to find and interpret connections between different quantities. Therefore, activities like using quadrats for ecology topics gives them the joy and opportunity to explore and find the connection between mathematics and nature in a playful way when they describe and analyse their findings via statistical analysis.

It is very common that 16- or even 18-year-old students do not know about the usefulness of STEM subjects. As they do not have much conception they have little or no knowledge of different areas of engineering or they think that physics is only for physicists and certain engineers. Significantly less misconceptions are present with life sciences and chemistry. Regular and well-planned visits to different industries and inviting academics to give presentations would further boost students' interests in STEM.

It is recommended that 11-14-year-old children learn separate areas of science (chemistry, physics, and biology) from subject specialists and in all areas teaching and learning is supported with regular field work, industrial visits and lots of group work activities.

14-16-year-old ones should be given the opportunity to specialise in the areas that they feel most interested in and during this period they might start experiencing more individual and independent learning that includes essay writing and problem solving associated with long term projects.

16-18-year-old ones become fully capable of being responsible for their own career planning and this period of studies. At the age of 18 the first exam style assessment could be timed but ideally there should be a choice between project or exam-based grading. Higher education institutions should not discriminate against either option.

CONCLUSIONS

In this study we have reviewed STEM education in different countries with different historical and sociological backgrounds, based on the available literature in the past decade and our practice-based research. Based on this a comprehensive analysis has been concluded in different regions with different historical and cultural backgrounds and from comprehensive evaluation, we have provided a STEM learning model that is based on collaboration and embedded constructivism in "learning-by-playing".

Our conducted experiments and surveys suggest that teachers have clear responsibility in shaping students' minds and their careers via their own STEM related enthusiasm. It has also been demonstrated that the initial lack of enthusiasm in primary school students was strongly related to their lack of confidence in the topics. However, with well-structured and scaffolded hand-on activities even the most reserved students became a lot more confident and start to actively participate in activities, especially when they were combined with artistic elements.

STEM education globally reflects a complex interplay of historical traditions, contemporary challenges, and future aspirations. Different regions demonstrate remarkable diversity in approaches and outcomes, from Hungary's strong mathematical pedagogical traditions to the Gulf countries digital leadership and vision 2030 programme and the UK's scaffolding structure and competitive excellence.

While significant challenges remain, including teacher shortages, funding issues or resistance to change, many countries show some progress in educational reform. The combination of strong mathematical and scientific traditions with innovative approaches to curriculum development and teacher preparation positions the region for continued improvement in STEM education outcomes. Successful STEM education experiences provide some valuable ideas, suggesting that collaborative approaches and practically embedded constructivism may offer the most promising path forward for enhancing STEM education globally.

Enthusiasm and passion are paramount to effective STEM education to be found in both educators and students. We conclude that playful learning via visual, engaging and creative activities in preschools and primary schools that can set young minds on a positive, long-term path in STEM would be worth testing globally as the potential benefits far exceed the minimal risks related to time investment in teachers' relevant professional development.

Author contributions: TK: conceptualization, formal data, formal analysis, writing - original draft, writing - review & editing; GH: methodology, writing - original draft. Both authors agreed with the results and conclusions.

Funding: No funding source is reported for this study.

Acknowledgments: The authors would like to thank active and retired professionals in the United Kingdom, Saudi Arabia, and Hungary.

Ethical statement: The authors stated that the highest ethical practices were followed during the study. All the data is fully and robustly anonymized, the participants gave consent for the anonymized answers to be published, and other data was fully available on public domain and anonymized.

AI statement: The authors stated that no AI tools have been used in the creation of the manuscript.

Declaration of interest: No conflict of interest is declared by the authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

REFERENCES

Abuhanasein, Y., Rejeb, A., & Jemai, K. (2025). Challenges to learning mathematical concepts among sixth-grade students in primary education: A teachers' perspective. *International Electronic Journal of Mathematics Education, 20*(2), Article em0819. https://doi.org/10.29333/iejme/15918

Bacsa-Bán, A. (2022). Vocational training in Hungary between 2010 and 2020. In *Proceedings of the INTED2022* (pp. 1093-1099). https://doi.org/10.21125/inted.2022.0338

Baikalizadeh, B., Derakhshan, M., Momeni, F., Taklif, A., Daneshjafari, D., & Javan, A. (2025). Saudi Arabian oil policies in vision for 2030 plan and its influence on the global oil market with a game theory approach. *International Journal of Nonlinear Analysis and Applications*. https://doi.org/10.22075/ijnaa.2023.29789.4263

Balázsi, I., & Ostorics, L. (2020). The Hungarian educational assessment system. In H. Harju-Luukkainen, N. McElvany, & J. Stang (Eds.), *Monitoring student achievement in the 21st century: European policy perspectives and assessment strategies* (pp. 157-169). Springer. https://doi.org/10.1007/978-3-030-38969-7

Bell, J. F. (1991). Science performance and uptake by 15-year-old pupils in Northern Ireland. *Educational Research, 33*(2), 93-102. https://doi.org/10.1080/0013188910330202

Bolton, G., & Delderfield, R. (2018). *Reflective practice: Writing and professional development*. SAGE.

Borrero, N. E., Flores, E., & de la Cruz, G. (2016). Developing and enacting culturally relevant pedagogy: Voices of new teachers of color. *Equity &*

Excellence in Education, 49(1), 27-40. https://doi.org/10.1080/10665684.2015.1119914

BouJaoude, S. (2020). STEM education in the Arab countries: Rationale, significance, and future prospects. In *STEM in science education and S in STEM* (pp. 213-241). Brill. https://doi.org/10.1163/9789004446076_010

Collinson, B. (2025). Without physics teachers in schools, there will be no medical physicists. *IPEM-UK*. https://www.ipem.ac.uk/news/without-physics-teachers-in-schools-there-will-be-no-medical-physicists/

Connelly, J. (2010). Hungary and the United States: A comparison of gifted education. *AHEA: E-Journal of the American Hungarian Educators Association, 3*, 1-8. https://doi.org/10.5195/ahea.2010.25

Driver, R. (1989). Changing conceptions. In P. Adey (Ed.), *Adolescent development and school science*. Falmer Press.

Durrani, N., & Kataeva, Z. (2025). STEM teachers' agency for gender equality in STEM education: A mixed-methods study. *International Journal of Educational Research, 131*, Article 102585. https://doi.org/10.1016/j.ijer.2025.102585

Dyachenko, A., Mukanova, R., & Erkibayeva, M. (2024). Integration of interdisciplinary connections between chemistry, physics, and biology in the education of secondary school students. *International Journal of Educational Reform*. https://doi.org/10.1177/10567879241290180

El-Deghaidy, H., & Mansour, N. (2015). Science teachers' perceptions of STEM education: Possibilities and challenges. *International Journal of Learning and Teaching, 1*(1), 51-54. https://doi.org/10.18178/ijlt.1.1.51-54

Engineering UK. (2025). A level and Scottish Highers results 2024. *EngineeringUK*. https://www.engineeringuk.com/media/jbxcj35s/a-levels-and-scottish-highers-results-engineeringuk-aug-24.pdf

FE News. (2024). Results day 2024: A level, T level and VTQ results are in! STEM surge and T level growth | sector reaction. *FE News*. https://www.fenews.co.uk/skills/results-day-2024-a-level-t-level-and-vtq-results-are-in-stem-surge-and-t-level-growth-sector-reaction/

Felicia, L. Y. X. (2023). Developing effective practice strategies. In G. Spruce (Ed.), *Aspects of teaching secondary music*. Routledge. https://doi.org/10.4324/9780203166970-16

Fosnot, C. T. (2005). *Constructivism: Theory, perspectives, and practice*. Teachers College Press.

Gibbs, G. (1988). Learning by doing: A guide to teaching and learning methods. *Further Education Unit*. https://thoughtsmostlyaboutlearning.wordpress.com/wp-content/uploads/2015/12/learning-by-doing-graham-gibbs.pdf

Gopnik A. (2012). Scientific thinking in young children: Theoretical advances, empirical research, and policy implications. *Science, 337*(6102), 1623-1627. https://doi.org/10.1126/science.1223416

Hallström, J., Norström, P., & Schönborn, K. J. (2023). Authentic STEM education through modelling: An international Delphi study. *International Journal of STEM Education, 10*, Article 62. https://doi.org/10.1186/s40594-023-00453-4

Kácovský, P., Jedličková, T., Kuba, R., Snětinová, M., Surynková, P., Vrhel, M., & Urválková, E. S. (2022). Lower secondary intended curricula of science subjects and mathematics: A comparison of the Czech Republic, Estonia, Poland and Slovenia. *Journal of Curriculum Studies, 54*(3), 384-405. https://doi.org/10.1080/00220272.2021.1978557

Karafyllis, N. C. (2015). Tertiary education in the GCC countries (UAE, Qatar, Saudi Arabia): How economy, gender and culture affect the field of STEM. In O. Renn, N. Karafyllis, A. Hohlt, & D. Taube (Eds.), *International science and technology education* (pp. 112-133). Routledge.

Kayan-Fadlelmula, F., Sellami, A., Abdelkader, N., & Umer, S. (2022). A systematic review of STEM education research in the GCC countries: Trends, gaps and barriers. *International Journal of STEM Education, 9*, Article 2. https://doi.org/10.1186/s40594-021-00319-7

Kertesz, A., & Rutai, L. (2023). With a chronic shortage of teachers, Hungary is struggling to replace them. *RFERL*. https://www.rferl.org/a/hungary-shortage-teachers/32475124.html

Klahrl, D., & Nigam, M. (2004). The equivalence of learning, paths in early science, effects of direct instruction and discovery learning. *Psychological Science, 15*(10), 661-667. https://doi.org/10.1111/j.0956-7976.2004.00737.x

Kogan, I., Gebel, M., & Noelke, C. (2012). Educational systems and inequalities in educational attainment in Central and Eastern European countries. *Studies of Transition States and Societies, 4*(1), 69-83.

Kozma, T., & Polonyi, T. (2004). Understanding education in Europe-East: Frames of interpretation and comparison. *International Journal of Educational Development, 24*(5), 467-477. https://doi.org/10.1016/j.ijedudev.2004.06.011

Kuhn, D. (1997). Constraints or guideposts? Developmental psychology and science education. *Review of Educational Research, 67*(1), 141-150. https://doi.org/10.2307/1170621

Larkin, K., & Lowrie, T. (2023). Teaching approaches for STEM integration in pre-and primary school: A systematic qualitative literature review. *International Journal of Science and Mathematics*

Education, 21(Suppl 1), 11-39. https://doi.org/10.1007/s10763-023-10362-1

Matthews, M. R. (2012). Philosophical and pedagogical problems with constructivism in science education. *Trema, 38*, 40-55 https://doi.org/10.4000/trema

Megreya, A. M., Hassanein, E. E. A., Al-Emadi, A. A., & Szűcs, D. (2025). Math anxiety mediates the association between gender and STEM-related attitudes: Evidence from a large-scale study. *Acta Psychologica, 253*, Article 104689. https://doi.org/10.1016/j.actpsy.2025.104689

Metz, D. (2016). Science education and citizenship. *Science & Education, 25*(3), 469-470. https://doi.org/10.1007/s11191-016-9815-9

Moon, J. A. (2013). *A handbook of reflective and experiential learning: Theory and practice*. Routledge. https://doi.org/10.4324/9780203416150

Muhammad, A. A. Samson, M. T., & Katherine, M. (2024). *STEM education–Recent developments and emerging trends*. IntechOpen.

Muhammad, T., Jibril, H. L., & Isah, F. J. (2022). Comparative analysis of science, technology, engineering and mathematics (STEM) education programs in the United Kingdom, United States of America. *Japan and Australia, Engineering and Technology, 3*(2), 191-211. https://doi.org/10.37745/bjmas.2022.0077

Munkácsy, B., & Scharle, Á. (2021). The relevance of future challenges to education in five central Eastern European countries. In P. Rado, B. Munkácsy, A. Scharle, & A. kende (Eds.), *Adapting to future challenges to education. Hungary, Poland, Romania, Serbia, and Slovakia* (pp. 15-60). CEU.

Murphy, S. (2020). Achieving STEM education success against the odds. *Curriculum Perspectives, 40*(2), 241-246. https://doi.org/10.1007/s41297-020-00110-8

OECD. (2020). *Education in Saudi Arabia*. OECD. https://doi.org/10.1787/76df15a2-en

Özoral, B. (2022). The effect of globalization in the Gulf countries and the changing roles of women: A comparative study on Arabia, The United Arab Emirates and Qatar. *Süleyman Demirel Üniversitesi Vizyoner Dergisi, 13*(36), 1150-1169. https://doi.org/10.21076/vizyoner.1069923

Pokropek, A. (2024). *STEM competencies, challenges, and measurements: A literature review*. Publications Office of the European Union. https://doi.org/10.2760/9390011

Quale, A. (2008). The game of prediction and retrodiction: A radical-constructivist perspective on the notion of time in physic. *Journal of Educational Thought, 42*(2), 105-125. https://doi.org/10.55016/ojs/jet.v42i2.52457

Robson, S., Harrington, L. M., Atkinson, K., Moon, A., Thompson, N., Kushner, J., Falgoust, G., Nguyen, A., Bicksler, B., & Zakzewski, J. (2025). Assessing needs for civilian STEM talent in the department of the air force. *RAND Corporation*. https://www.rand.org/pubs/research_reports/RRA3170-1.html

Rose, M. F., & Joyce, D. (2018). Defence youth STEM outreach–Inspiring the next generation. In *Proceedings of INEC*. https://doi.org/10.18653/v1/K18-2019

Scager, K., Akkerman, S. F., Pilot, A., & Wubbels, T. (2014). Challenging high-ability students. *Studies in Higher Education, 39*(4), 659-679. https://doi.org/10.1080/03075079.2012.743117

Silova, I. (2009). Varieties of educational transformation: The post-socialist states of Central/Southeastern Europe and the former Soviet Union. In R. Cowen, & A. M. Kazamias (Eds.), *International handbook of comparative education* (pp. 295-320). Springer. https://doi.org/10.1007/978-1-4020-6403-6_19

Singapore Maths. (2025). What is Singapore math? *Singapore Maths*. https://www.singaporemath.com/pages/what-is-singapore-math

Smith, E., & Gorard, S. (2011). Is there a shortage of scientists? A re-analysis of supply for the UK. *British Journal of Educational Studies, 59*(2), 159-177. https://doi.org/10.1080/00071005.2011.578567

Smith, E., & White, P. (2025). Gender, participation and attainment in STEM: A comprehensive overview of long-term trends in the United Kingdom. *British Educational Research Journal, 51*(2), 802-825. https://doi.org/10.1002/berj.4102

Szakács, S. (2018). *Europe in the classroom: World culture and nation-building in post-Socialist Romania*. Palgrave Macmillan. https://doi.org/10.1007/978-3-319-60258-5

Taber, K. S. (2017). The nature of student conceptions in science. In K. S. Taber, & B. Akpan (Eds.), *Science education: An international course companion* (pp. 119-131). Sense Publishers. https://doi.org/10.1007/978-94-6300-749-8_9

Thompson, E. (2024). 2024 A-level results: Significant increase in STEM subject uptake signals positive trends in UK science and technology. *EdTech Innovation Hub*. https://www.edtechinnovationhub.com/news/surge-in-stem-a-level-entries