Science, technology, engineering and mathematics education: overcoming challenges in Europe

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Foreword

Context of this paper

This paper has been drafted by European Schoolnet, the European network of 30 Ministries of Education with extensive input from Intel® and the support of reviewers from Danish Science Communication, EngineeringUK, European Round Table of Industrialists, the Institute of Education, Science in School magazine and Science on Stage Europe.

It is the culmination of debates at the three-day Intel Educator Academy EMEA, held on 10-12 March 2011, which brought together leading science, technology, engineering and mathematics (STEM) educators, policy makers, business and industry to openly share ideas, best practice and insights into STEM education from across Europe, the Middle East and Africa (EMEA).

The event was held in conjunction with the UK’s Big Bang Fair, organised by Engineering UK.

Aims of this paper

This white paper outlines the state of STEM education in the EMEA region, and suggests steps locally and across participating countries in order to benchmark and increase future participation in STEM studies and careers. It is widely acknowledged from major European and global studies such as TIMMS, ROSE, Eurostat and PISA that many countries are suffering from low achievement and low interest among students in STEM subjects and STEM-related careers compared to others across the world. This problem is particularly acute in Western European countries.

Indeed, despite some countries (e.g. the UK) showing a small positive increase in recent years, the region’s future competitiveness in innovation is in peril, as the ERT combined benchmark of achievement, interest and demographic change relating to STEM continues to show a downward trend in the next few years, unless major systemic changes are introduced in both formal and informal STEM education to mitigate this decline. This paper tackles this issue by outlining key priorities and successful models for scaling up STEM enrichment and enhancement activities within the informal field – e.g. science fairs and festivals – as well as formal STEM education through schools and universities.
Knowledge and competency in STEM is a crucial skill

The STEM skills gap in European EMEA countries compared to other regions across the globe is widening: in Asian countries STEM students can account for up to 20% of the student population, whereas in Europe, this percentage is only around 2%.

In African and Middle Eastern countries, STEM interest among students is very high, but the quality of teaching and learning in the field is not at the same level. At a time of economic crisis, where the ICT sector is one of the only sectors still demonstrating growth, knowledge and competency in STEM has become a crucial key skill. On one hand, providing individuals with a wide range of exciting future career paths, and on the other, providing governments a route to sustainable economic growth and stability by stimulating innovation, R&D and ultimately services in STEM fields.

At the event, the experts agreed on several key factors which have led to this unfortunate situation and highlighted those that should be addressed as a priority:

1) Negative perception: inaccurate stereotypes exist around the STEM sector and its role in society: on one hand as regards STEM itself, which is not perceived as a voyage of discovery, but rather as a dry, fact-based subject; on the other hand, in relation to gender and minority participation in STEM, more diverse role models need to be promoted to ensure that diverse populations understand they can participate in STEM.

2) Lack of policy connectivity: significant disconnects exist between government policies and practice by business and industry: governments often emphasise STEM in political priorities but it is not usually backed up with investment at sufficiently early levels of education (i.e. funding usually focuses on university level research), while industry’s role in STEM education is varied and non-systemic.

3) Lack of inspiration: widespread low engagement and pursuit of STEM careers among young people in large part due to a negative experience of STEM at school, where young people often find STEM subjects difficult or boring, science classes fail to inspire them and they do not find that STEM resonates with their self-perception.

4) Poor up-to-date educator support: lack of relevant support and training for teachers: particularly in terms of staying up to date with current scientific theories and discoveries, and knowledge of what industry actually does, as well as new teaching methods at secondary level, while primary teachers often feel uncomfortable tackling scientific topics as STEM is rarely their field of specialisation.

The forum also highlighted several functions and visions of STEM education, which echo Morrison’s model (2006), illustrated in the box below.

Which skills should a STEM student develop?

- Problem-solving – able to define questions and problems, design investigations to gather data, collect and organise data, draw conclusions, and then apply understandings to new and novel situations.
- Innovation – creatively use science, mathematics, and technology concepts and principles by applying them to the engineering design process.
- Invention – recognize the needs of the world and creatively design, test, redesign, and then implement solutions (engineering process).
- Self-reliance – able to use initiative and self-motivation to set agendas, develop and gain self-confidence, and work within time specified time frames.
- Logical thinking – able to apply rational and logical thought processes of science, mathematics, and engineering design to innovation and invention.
- Technological literacy - understand and explain the nature of technology, develop the skills needed, and apply technology appropriately.
Based on these premises, the attendees at the Educator Forum tackled a set of main problems, which could address these issues, namely:

- How can STEM teaching and learning be reformed to enhance engagement and uptake of STEM studies, at national and international level?
- How can educators and industry players fight the main stereotypes around STEM education and careers?
- How can students with potential be identified and supported to fully realise their potential while also ensuring long-term motivation for STEM?
- How can educators and educational institutions be supported in implementing innovative and engaging approaches to STEM education?

This paper aims to examine these questions with a view to providing a strategic framework for enhancing STEM education in Europe.

The challenge of STEM education is varied and impacted by many diverse socio-economic factors. The diagram below indicates some of the key factors which impact on student interest, motivation and career choices:

1. Defining a collaborative environment: ecosystems and partnerships

This diagram indicates how diverse and complex the factors are that can influence students’ interest, motivation and ultimately their choice for STEM studies and STEM careers. This diagram explains the issue only in schematic form: many of the factors interact across the various areas of influence, e.g. role models although personal, can be parents, teachers, scientists or engineers visible in the media. These factors not easily addressed by only one type of organisation or initiative; they require engagement and complimentary input from a broad range of stakeholders, outlined in the table below (personal factors have been excluded as these can only be influenced indirectly, through the two other key factors).
The above table demonstrates the complexity and wide range of partners that a systemic approach to the STEM challenge would have to encompass. Currently, each type of stakeholder, although active, has developed some responses to the challenges, but often in isolation, or in small groups that are unable to stimulate the system-wide change required.

Notably and perhaps of necessity if we are to break the downward spiral, this group of stakeholders goes far beyond the scope of traditional public-private partnerships, which typically engaged primarily government actors with private partners, and where private partners acted as financial sponsors of private partners, and where private partnering typically engaged primarily government actors with private partners, and where private partners acted as financial sponsors of private partners. Some former Communist countries – for instance Jet Net in the Netherlands, and very rarely in Africa and the Middle East. They have had a proven influence on the situation. However until 2011 such partnerships did not cooperate systematically on an international level. The European Coordinating Body for STEM education, known as InGenious, set up by the European Round Table of Industrialists (and their member companies), European Schoolnet, the European Commission and associate member companies including Intel, Microsoft, SMART and others is a new example of such international partnerships. It aims to foster long-term cooperation and assist countries in enhancing national multi-stakeholder activities in STEM education. Such partnerships need to be extended and widened to ensure mainstreaming of their activities in the informal and formal education systems, and to work through both top-down and bottom-up measures to have a high impact. The key outcomes to be addressed by these partnerships are to ensure:

- Wider participation from all stakeholders, including public and private sectors, research centres, science centres and museums, and community leaders
- Integration of all levels of STEM implementation from formal to informal education, and from student to policy maker
- The establishment of comprehensive and coherent goals in a collectively built STEM education strategy that takes all major factors into account, underpinned by a strong, relevant evaluation approach built around key indicators of STEM interest, knowledge and engagement strongly integrating both education and careers.

2. STEM in schools: curriculum, pedagogy and assessment

A major challenge in STEM education relates to the experience of young people having during STEM classes. Students often complain that STEM is difficult, boring and not relevant to their every day lives. Why do young people make these assertions about STEM?

As regards to difficulty, STEM concepts are not always easy to grasp – particularly when dealing with dynamic concepts that cannot easily be illustrated in a textbook. Simulations and experiments can certainly assist young people's learning as the Intel School programme demonstrates. It is widely accepted that all STEM subjects require a good grounding in mathematics – a subject strongly influenced by gender-related perception (except in a few rare countries such as Portugal and some former Communist countries) – indeed in many such countries STEM in general is considered appropriate for girls. Mathematics pedagogy is one of the most uninspiring and traditional areas of schooling and requires significant enhancement to increase achievement and understanding among students. Finally, there is also evidence that many curricula are "over-stuffed" with factual content: more and more topics are added while few are removed. This can lead to students having the impression that STEM is about factual recall, rather than understanding the scientific method of observation, hypothesis and experimentation. The issue of difficulty is particularly acute at secondary level – often because students leave primary school with insufficient scientific grounding. Primary teachers are often uncomfortable teaching STEM topics as in the main they are not themselves qualified in a high level STEM subject and therefore particular attention is needed to ensure they are appropriately trained or supported through supplemental programmes (e.g. Primary Engineer in the UK where a non-profit association provides content and support to primary teachers). Reinforcing the links between primary and secondary teachers of science could also help address the challenges of the challenging transition years in STEM at upper primary and lower secondary.

Students also express boredom in science lessons due to their experience of STEM teaching and learning, and the relevance of content to their lives and future careers. In some STEM lessons, an over-reliance on examples that inspire male students (e.g. transport, heavy industry) dissuades girls who are often motivated by scientific applications related to the environment and medicine (Eurydice, 2011). However, across the whole field of STEM, pedagogy certainly needs attention, moving from text-based, factual recall to more exploratory learning models such as inquiry-based learning, scientific experimentation, scientific debate and collaborative learning (Rocard, 2007). ICT use is often limited in STEM education and the use of ICT-based STEM pedagogy has a positive impact on student motivation particularly for the younger age groups (e.g. through use of digital learning resources online, use of data-logging equipment to observe experiments in real-time – LeBlanc et al. and Cáceres et al., 2009). Problem-based learning – promoted for example by the Intel Teach programme - where students are invited to devise
responses to specific problems, also has a strong impact on motivation and can particularly increase interest in engineering.

Finally student motivation and interest remains relatively low because they struggle to link school STEM experiences to their lives. Although young people are often avid consumers of STEM products – for instance, ICT tools such as smart phones and computers – such interest is rarely used as a point of departure for STEM teaching and learning. Similarly, they often fail to see how STEM relates to society’s current challenges such as climate change, biodiversity loss and energy production. In countries where curricula do focus on such issues as an entry to basic science concepts, young people are more interested and motivated to study STEM at later stages in their lives. Linking these kinds of topics with industry experts (for example via the Xperimania programme from the European Chemical Industry Council where students can debate with experts online or invite experts to visit schools for workshops) can also help reinforce the understanding of science’s role in society. Such an approach also allows more cross-curricular integration of STEM topics, which demonstrate how, in the real world, various scientific disciplines come together to solve problems.
The role of science fairs and events in stimulating interest in STEM topics and careers

Given the difficulties of interesting students in STEM through formal school teaching, the role of science and engineering fairs – typically comprising student-led STEM exhibits, combined with competition elements to reward the best student exhibits and exhibits from other STEM actors such as associations and businesses – is particularly important.

There is a network of science fairs, supported by Intel, taking place across Europe (and indeed now globally through the link from EU level to the Intel International Science and Engineering Fair organised by the US-based Society for Science), which link together into a European final level event, the EU Contest for Young Scientists (EUCYS). The EUCYS links to national science fairs in each country, where awards are given at national level including The Big Bang Fair in the UK, “I giovani e le scienze” (“Youth and Science”) in Italy, “Unge Forskere” (“Young Scientists”) in Denmark, “Jugend forscht” (“Youth research”) in Germany and Eastern European events such as the AMAVET Science Fair, Festival of Science and Technology in Slovakia.

In such events, small teams of students (usually at secondary level) are invited to research and develop STEM projects of their own choice over several months, which they then display at the event. Often preparation of STEM fair projects is done through after-school science clubs or in personal time.

Benefits of such fairs include:

• Strong ownership among students of their project and results
• Independent work by students and increased confidence in their work (good preparation for university)
• A shift from teacher-directed learning in science towards hands-on, experimental and problem-based learning, with a need for collaborative team working and cross-curricular use of science knowledge and skills
• A clear link between STEM activities and STEM careers.

There are however some key challenges in the current operations of science fairs which need to be addressed:

• As teachers rarely integrate such projects into normal class activities, only students who are motivated to engage beyond the classroom benefit.
• As the projects are chiefly tackled outside school, those students with home environments that encourage STEM (e.g. if parents are working in scientific careers), or are existing high science achievers can be disproportionately advantaged compared to students whose family awareness of STEM is not as conducive to understanding the value of engaging with extracurricular activities.

Schools and ministries of education should thus consider better integrating science fair projects within the school day, to bring the benefits to all types of student and to a larger number of students, i.e. inclusive rather than exclusive. Some curricula currently preclude this, while others require student-research projects as part of formative assessment – the latter are better suited to wider scale uptake of science fairs.

Science on Stage Europe coordinates the European level, while national partners run local activities. For these events, the impact on teachers is positive especially in terms of gaining new pedagogical ideas and approaches from their peers. However, although impressive – reaching 40,000 visitors saying they would recommend a visit to others. The combined force of all stakeholders working together also has a much higher media impact than a more traditional science fair; in parallel the engagement with STEM businesses has grown significantly as a direct result of being able to prove impact via its robust evaluation process.

"Both careers and fun STEM content are brought together through an exhibition, workshops, a student competition and awards ceremony."

1 https://ec.europa.eu/research/youngscientists/index_en.cfm
Equipping teachers to better address the challenge of STEM teaching and learning.
Equipping teachers to better address the challenge of STEM teaching and learning

The challenges of teaching and learning STEM topics are widespread, and STEM teachers are now an aging population, with the result that the age gap between students and teachers is growing. At the same time, STEM developments in industry and research move quickly, so STEM teachers require – and indeed seek – ongoing professional training to stay on top of their subjects.

This willingness among STEM teachers to engage in continuing professional development (CPD), ideally through regional expertise centres such as the Science Learning Centres in the UK, offers an opportunity to enhance the effectiveness of STEM teaching and learning. Rather than focusing only on updating topic knowledge, teacher training in STEM – whether in-service or at pre-service level – needs to cover:

- **A new approach to STEM pedagogy**: moving from fact-based recall to student-centred approaches, bringing together a variety of proven motivating pedagogies such as inquiry-based learning, problem-solving and collaborative work.

- **How to adjust pedagogy to support a diverse student population**: teachers (and indeed publishers and curriculum developers) need to adjust their approaches to include issues which are more attractive to relatively excluded populations such as girls, ethnic minorities and low achievers. This could range from using a wider set of role models and illustrations in teaching materials, to integrating topics with a more general interest, to taking account of STEM’s wider global impact and its associated ethical, legal and societal issues.

- **Introduction of more hands-on based approaches**, including new forms of experimentation (e.g. school lab experiments that could include new topics such as nanotechnology) and the integration of ICT-based methods (use of sensors, data loggers, simulations, online collaboration, etc.)

- **Integration of formal and informal approaches to STEM education**: e.g. engaging in international projects and science fairs, science museum-led projects, engaging local businesses and industry in science education via partnerships and site visits in research facilities.

- **Transferable good practice**: examples of concrete teaching approaches which have worked in other schools, which can easily be adapted and reused in other schools.

Although traditional CPD is important, increasingly evidence implies that such training is not sufficient to bring about real change. CPD needs to be supported through other forms of teacher motivation, for instance via:

- **Engagement in informal networks of teachers**, sharing practice and offering concrete tips and tricks to use in the classroom. These could be via traditional science teacher associations, and informal networks such as Science on Stage Europe or through online communities such as eTwinning (a European network of more than 150,000 teachers) or Intel’s Skool platform.

- **Rewarding teachers who innovate and implement good teaching and learning approaches, and share their results for example**:

  - Through competitions e.g. the Science on Stage fair, or Teacher of the Year awards. Offering prizes which allow them to enhance STEM teaching in their schools can reinforce the impact, e.g. additional STEM equipment, seed funding for a science club or further training opportunities.

  - Through career evaluation and school inspection processes that reward and support innovation rather than acting as an obstacle.
Conclusions and recommendations

Improving the interest and motivation of students for STEM education is a multi-faceted and complex issue. To ensure concrete and effective enhancement of the situation, a range of new approaches need to be implemented and “islands” of innovation and good practice need to be extended and mainstreamed.

Recommendation 1: Establish and enhance sustainable multi-stakeholder partnerships to combine forces to tackle the challenges of STEM education

This should be put in place by a variety of approaches, launched through the establishment and enhancement of multi-stakeholder partnerships – at both national and international level – to bring together government (all sectors concerned from ministries of education to those responsible for science, technology and research, and authorities with responsibilities from national to local level), industry, research, communities, associations and science communication stakeholders, as well as the media who are so important in spreading messages to wider society, and changing the vision of STEM. These partnerships need to be sustained over a long period to bring about real change on the ground at the level of students and teachers, and be underpinned with ambitious and strategically built plans to ensure coherent actions across the various stakeholder groups. The focus should be on identification and sharing of approaches which bring measurable change to students but also to develop new approaches where needs analysis identifies gaps. They should be explicitly linked to achievement in both traditional STEM indicators but also to more innovative competence-led 21st century skill sets, through reliable and rigorous research and evaluation mechanisms. Mainstreaming is also essential – government here has a key role to play in ensuring that the “average” school and “average” student have opportunities to engage in innovative approaches to STEM teaching and learning.

Recommendation 2: Enhance and reform STEM curricula, pedagogy and assessment

Change needs to occur at grassroots level; so schools must be a primary focus of new programmes to enhance curriculum, pedagogy and assessment in the field of STEM. In many countries across EMEA, revision to school STEM curricula is very long overdue: on one hand to include the latest developments in scientific research and on the other, to better integrate issues of real interest to a diverse and gender-balanced student body. More flexibility is also required to enable teachers to innovate and inspire. This implies changes in text books and teaching resources to ensure schools have the right tools for the job. Newer forms of pedagogy including inquiry-based, hands-on and ICT based approaches must be adopted on a wider basis, and be encouraged and supported through the school system – and a move away from “fact-based” towards “competence-based” assessment is essential. Building links between schools and other stakeholders such as industry, science museums and associations is key to ensuring that teachers and schools receive the support they need to do this.

Recommendation 3: Embed science fairs and festivals in the mainstream of school activity

Science fairs and festivals not be seen as an optional extra for bright students, but as a motivating tool to engage even those students who are lagging in STEM studies. Science clubs and informal mechanisms to support teachers and students as they prepare projects for science fairs need to be better supported by the formal education system to ensure more equal access to informal science learning opportunities after the school day. Teachers should also be encouraged to take a creative approach to the curriculum, and to develop methods to include self-driven student research projects as part of STEM lessons.

Recommendation 4: Offer more support to STEM teachers

Teacher training should be enhanced and upgraded at both pre- and in-service level, and more use of informal peer-based learning should be used too. Teacher training needs to better integrate new forms of pedagogy in STEM, as well as new mechanisms for teaching and learning such as integrating outside experts, ICT-supported methods and moving from a “sage on the stage” to a more coaching-based role. Specific training must to be given to teachers to adapt their methods to meet the needs of a diverse student population, including the traditionally excluded groups. More informal and formal rewards need to be put into place from both public and private sector to encourage the spread of excellent teaching ideas and approaches.

Recommendation 5: Learn from and build on excellent approaches

To conclude, although the challenge of motivating more students for STEM studies and careers is not trivial, there are plenty of excellent approaches in Europe which are perfect starting points for tackling the problem in a more systemic way. Better links between these approaches – through events such as the Intel Educator Academy - supporting them financially through public-private partnerships and mainstreaming them across the region will bear much fruit in the future. There is strong potential for improving the situation for all students and teachers, given the right levels of commitment from all stakeholders.

Finally, if we are to have any hope of addressing the larger grand challenges of global health, food security, biodiversity, water security, population and sustainable energy use then we simply cannot afford to fail in our ambitions to overcome the challenges that have been described in this white paper.