INNOVATIVE STEM TEACHING: THE LATEST TRENDS IN STEM EDUCATION

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Abstract

Innovation in STEM education is not easy to define, and the COVID-19 pandemic showed how digital approaches are key to innovation in schools. Nevertheless, the focus on innovation should not stop with tools and technological solutions, but rather integrate methodologies and pedagogical approaches where students are at the centre of the learning process. To achieve this, capacity building for teachers is needed to develop soft skills and give them holistic perspectives that will allow them to find solutions to today's problems. STEM education should help students to better understand our world. Classic approaches such as STE(A)M or a holistic approach to STEM offer opportunities for collaboration, creating projects beyond the classroom. The latest trends in STEM education (immersive learning, virtual experiences, creating content, sharing, and reflecting on their own, hands-on activities, and outreach programmes integrating families in the learning process) create some challenges and many opportunities in education. For example, bridging the digital and gender gap involves all students in STEM education. Choosing the right approach or methodology in STEM teaching is equally important to how school systems address the lack of time and flexibility of curriculums. These two aspects are essential for STEM education to be innovative.

Keywords: STEM education, innovation, STE(A)M, technology, creativity

The work presented in this document has received funding from the European Union's H2020 research and innovation programme – project Scientix 4 (Grant agreement N. 101000063), coordinated by European Schoolnet (EUN). The content of the document is the sole responsibility of the organizer, and it does not represent the opinion of the European Commission (EC), and the EC is not responsible for any use that might be made of information contained.

Introduction

Innovative processes and approaches and educational technologies improve science, technology, engineering, and mathematics (STEM) education because they encourage students to use different strategies to solve problems. Innovation does not mean creating something from nothing but relaying on existing good practices to move education forward. For example, innovative STEM teaching can offer new ideas to attract students more towards STEM, close the gender gap, and encourage hands-on learning.

'Innovative STEM' is not easy to define, but we can distinguish several dimensions as far as innovation is concerned. Some authors refer to cross-disciplinary[1] or interdisciplinary[2] methodologies. A recent evolution in STEM has been the integration of arts into STEM teaching, leading to innovative STE(A)M, which stands for science, technology, engineering, the arts, and mathematics, but the (A) can also refer to all subjects. Educational technologies can also contribute to bringing innovation into STEM teaching and learning. Outreach programmes[3] and STEM teaching through non-formal learning[4] and makerspaces are also seen as innovative. Other authors think that big picture education (BPE)[5] might be a response to the lack of interest in STEM subjects. Innovative STEM could also refer to creative and engaging teaching and learning methods such as using dance for teaching mathematical concepts[6].

The STNS entitled 'Innovative STEM Teaching: What are the latest trends in STEM education?', held online on 12 October 2022, aimed to explore the latest trends in STEM education and how to implement them in the classroom. The seminar brought together a diverse group of stakeholders to exchange knowledge and good practices and to set the grounds for new partnerships and collaborations. This included representatives from ministries of education (MoEs), industry, teachers, policymakers, researchers, teacher trainers, NGOs, education networks, and consultants.

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[1] Cross disciplinary: viewing one discipline from the perspective of another.
https://www.arj.no/2012/03/12/disciplinarities-2/
[2] Interdisciplinary: when two disciplines work together towards a goal.
https://www.researchgate.net/post/What-is-the-difference-between-multi-inter-and-transdisciplinarity
Or integrating knowledge and methods from different disciplines using a real synthesis of approaches.
https://www.arj.no/2012/03/12/disciplinarities-2/
[3] Outreach programmes are partnerships between schools and corporations, organisations, or research institutions. They help bring the (human) resources of the partnering institutions into the classroom.
[4] Informal learning refers to learning that occurs away from a structured, formal classroom environment.
[5] With BPE, the teaching and learning starts from each student's interest and needs.
[6] http://www.shineforgirls.org/shine-formula

This paper shares the main outcomes from this seminar, combining a literature review based on the research, educational programmes and projects mentioned by the attendees during the discussions in the seminar, and attendees' observations in their personal and professional lives around the topic of innovation in STEM learning and teaching. By combining theory, research, and practice, the paper offers a unique account of the European landscape of initiatives, projects, interventions, and actions that could be taken to introduce innovative STEM approaches in schools.

What makes STEM education innovative?

Some authors see STEM as a cross-disciplinary learning design to engage students in applying integrated knowledge to complete a project or solve a complex problem (Chang et al., 2021). Guerrero et al. (2018) describe an innovative STEM education framework for preparing secondary mathematics teachers called NAUTeach, a research-based STEM programme that provides a broad, cross-curricular[7] framework of innovative instruction. The programme focuses on 'inquiry-based instructional methods, reflective practice, and peer collaboration through courses that promote field work and a learner-centered focus of teaching and learning'[8]. It is a blended mathematics and science teacher preparation programme that allows students to develop deep content knowledge in their chosen field with the ability to apply this knowledge in several different field-based practicum[9] situations. The teacher candidates collaborate with mentor teachers to discuss the content instructions and lesson plans. The lessons are implemented in a middle school classroom, thus giving the future teachers the opportunity to connect their planning and teaching to the theory in a genuine classroom situation.

For Lenovo, innovation means empowering teachers and inspiring students, so they feel excited about learning. STEM can help them better understand the world and puts everybody on board of education.

In 2013, the American Association for the Advancement of Science defined 'transdisciplinary' as 'the dismantling of disciplinary boundaries, rather than ad hoc collaborations, that could transform the scientific enterprise and deliver the potential to address previously intractable problems' (p. xii.) (Back et al., 2015). Others see it as fusing or mixing disciplines. Back et al.

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[7] Cross-curricular: relating to or involving different courses offered by a school. https://www.merriam-webster;com/dictionary/cross-curricular
[8] Guerrero et al., 2018, p. 1
[9] Practicum: a course of study designed especially for the preparation of teachers, involving supervised practical application of previously studied theory.

(2015) maintain that this approach, through modules and collaboration of students across disciplines, and the input from outside experts, is the best way to prepare students for addressing the interconnected problems of today's society.

Particularly in multicultural classes, STEM in combination with content and language integrated learning (CLIL) and technology turned out to be an innovative approach, which not only increased students' motivation but also developed the European key competences and promoted integration (Schietroma, 2019).

There are also several European projects that see STE(A)M as innovating STEM learning. For example, the STE(A)M IT project created the first European integrated STEM framework[10], and Make it Open[11] combines the open schooling and maker pedagogies to enhance collaboration between schools, students, families, and stakeholders who not involved in formal education. The problem-based learning approach developed by Make it Open relies on hands-on and collaborative experiences to stimulate learners' imaginations and empower students, who start considering themselves as problem-solvers and change-makers. The project supports schools in their transformation into open educational spaces and provides resources for teachers and students. Through the citizen science approach, the SEEDS project[12] aims to empower teens in managing their health. The main characteristic of citizen science is to produce scientific results with an alliance between scientists and people (not professionally related to science). The project is directed at young people collecting data related to their health (physical activity, eating habits, etc). They analyse and interpret the data and communicate their findings to the rest of the world, following the scientific method. SEEDS ambassadors are protagonists in all these steps. They meet and discuss the different arrangements[13].

According to the Organisation for Economic Cooperation and Development (OECD), innovation skills encompass both soft skills and technical skills. It is very often the focus on the former that is lacking in formal education. That is why the Association of Science and Technology Centers (ASTC), in collaboration with the Flemish department of Education and Training, wanted to find out how science centres can play a larger role in bridging the gap between young people and their future world of employment and provide them with the skills to become innovators when they get a job. The report (Kirsch, 2015) was based on focus groups in 11 countries with partners from education, industry, and science centres that had to discuss 11 statements. There was a consensus that for science centres to be effective and

[10] https://steamit.eun.org/
[11] https://makeitopen.eu/
[12] https://seeds-project.org/
[13] Final video of the SEEDS's project: https://www.youtube.com/watch?v=jdOg3jj_NWQ

innovative, there should be a link with industry as applications in industry are, in fact, the implementation of science and technology in real life. Science centres were especially beneficial for acquiring soft skills such as teamwork and creative thinking. However, all focus groups agreed that these technology centres are only effective for STEM learning if the mediators at the centre have a sound theoretical knowledge to explain the exhibits at the science centre. Moreover, the visit(s) to the science centre should be integrated into the curriculum with a theoretical introduction before the visit, and a reflection and assessment phase afterwards. Another example of an innovative STEM approach is the SHINE for Girls[14] initiative, an after-school programme founded in the US that combines the art of dancing with mathematic instruction to help young girls become confident and capable mathematicians.

Innovative use of technology in STEM education

Innovative STEM education is sometimes considered as STEM using technology. However, a mathematics class can be supported by technology whilst still being taught in a traditional way. Using technology can only be innovative if it provides new, meaningful, and sustainable solutions to real educational needs. The previous Scientix ‘STEM goes Digital’ STNS (Bilgin. et al., 2022) concluded that there are many advantages of using technology in the classroom.

The OECD Centre for Educational Research and Innovation (CERI) used the HP Catalyst Initiative as a case study to find out how technology-supported learning can help to go beyond content delivery and enhance STEM education (Kärkkäinen & Vincent-Lancrin, 2013). The authors explored five technology-supported pedagogical models; gaming, virtual laboratories, international collaborative projects, real-time formative assessment, and skills-based assessment that had emerged from the HP Catalyst Initiative. They wanted to find out which models have the potential to improve students’ learning outcomes and their deep-thinking skills, and also offer a wide range of learning opportunities. They point out that technology can be seen to increase collaborative learning. This collaborative learning could not only take place between students, teachers, classes, and schools at a local level but also internationally. Thus, collaboration through technology may improve flexibility, cultural diversity, student learning, student interaction and engagement, and students’ higher-order thinking skills.

Through their research, De Smet et al. (2014) showed that the way content is visually represented when using new technologies such as massive open online courses (MOOCs) is very important. However, they did not find evidence for the relevance of collaborative learning,

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[14] http://www.shineforgirls.org/

contrary to other authors (i.e., Guerrero et al., 2018). Moura Santos & Fleming (2019) think that the best way to develop MOOCs is by using an interdisciplinary team.

Knowledge about learning spaces is a great resource for teachers to improve their students' learning experiences. For example, an agricultural STEM project made students use augmented reality, Google Earth, and geographical information systems, which had a positive impact on their knowledge and interest (Vallera & Bodzin, 2020). Virtual laboratories and simulations can enable teachers to organise engaging hands-on STEM activities without the need for expensive laboratory equipment at school (Bogusevchi & Muntean, 2020). Simulations are effective and more efficient when they include some learner scaffolding and feedback elements (D'Angelo et al., 2014). Virtual reality (VR) is another technology that can create a hands-on experience for students. VR is said to be immersive, therefore it can engage students and help them to retain learned material and manipulate and inspect 3D objects. However, unlike virtual labs, VR equipment can be costly. Furthermore, it offers a rather individual experience, with few possibilities for collaborative learning (Pellas, Dengel & Christopoulos, 2020). Open-source educational environments or platforms (such as Moodle or Graasp) and free and open access materials and tools (virtual laboratories, apps for mobile devices, etc.) are the most appropriate for all schools because they are 1) available for everyone everywhere; 2) avoid socioeconomic discrimination; and 3) foster life-long learning opportunities.

When schools faced the COVID-19 pandemic, they realised they had to adapt very fast and start teaching digitally. Technology improved interactions between teachers and students in this situation, supported personalised learning, and provided an opportunity for teachers to be more effective professionally. This led to a digital transformation of schools and proved that every student needs to have digital skills, not as a separate discipline that they do at school but as part of how they learn, and it showed that teachers need better preparation too.

Tampere University gathered some data during the COVID-19 pandemic and differences in digital skills between schools and pupils increased a lot. Vainikainen et al. (2022) observed that the COVID period may have compromised educational equity in Finland. According to a nationally representative survey, educational equity was, to some extent, compromised during the COVID-19-related school closures in Finland, a country otherwise known for its well-functioning education system and low school segregation (Vainikainen et al., 2022). In particular, the level of structure and dialogue received by pupils varied more between schools compared to the pre-COVID era. There were also indications that schools with a higher concentration of socio-economically disadvantaged pupils may have had greater difficulties in maintaining the quality of education during distance learning caused by the pandemic. The differences observed may be able to be explained by teachers' varying digital competences and the availability of devices and resources.

Another example from the City of Helsinki regarding the use of data and AI to improve education shows how to identify pedagogical use cases where technology can support the 'well-learning' vision[15].

A great effort has been made in the last few years by the education systems to support (e.g., selection, purchase, and management) the use of innovative approaches for STEM education in schools. Educational systems promote innovation in the new curricula, but in some cases, these changes need a significant effort in teacher training to get successful results. Educational administrations must make more effort to acknowledge and recognise innovative practices and teachers as a way of professional development.

The latest trends in STEM education

STEM education brings a mixture of different perspectives as it involves:

1. **Methodologies** and the contextualisation of the learning activities. The innovative perspective of STEM is strongly related to methodology. JA Europe[16] integrates STEM education in their programme – primary and older. Although it might be difficult to introduce some STEM concepts at primary level, educators need to emphasise why it is important. This also applies to high school and university students who need to understand why STEM skills and knowledge play a key role for their future careers, especially soft skills, which are key in teaching technical skills. They should also be aware of how to use technology wisely, and how it may help them progress, either in their future education or career paths.

2. Placing the **student at the centre** of educational procedures and processes. Teachers should also integrate STEM education into their classrooms. It is not only important to teach students what STEM is, but it is also crucial to encourage them to empathise with real-life situations and problems. There are many digital tools and technologies that could be used for this purpose, but students should understand why and when to use it. It is a step towards a global and holistic mindset in which all subjects work together to develop students' critical thinking, problem solving, and innovation skills. Taking many small steps in primary school, making students understand what is happening, and going forward from that.

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[15] https://customers.microsoft.com/en-us/story/1477362858581906559-helsinki-k12-edu-azure-en-finland
[16] http://www.jaeurope.org/

3. Emphasising **inquiry, observation, interaction** with physical phenomena, and experimentation more than descriptions of facts. Emphasis on hands-on experiments. STEM education is much more than an educational approach and methodology. It is a way of thinking and learning that will lead to a mindset growth. STEM education can help students make connections between what they learn and the real world. To innovate, there needs to be time and space for creativity and opportunities to develop critical thinking. Students don't only need to have ideas, but they should also develop their ability to choose the appropriate ones. Moreover, STEM education puts students at the centre of the learning procedure and promotes collaboration.

4. **Empowering students and their families to connect them with real-life problems** for pupils to better understand their world. Society not only needs a future workforce, but better-equipped citizens too. Beyond thinking about their career choices, students should develop skills for themselves as well. Two elements that are important to integrate and make STEM innovative are: (1) having an analytic view of how to better understand the world and (2) including parents in STEM education. Lenovo[17] led a workshop with teachers about the Sustainable Development Goals (SDGs). During this workshop, educators expressed how parents need to be involved in STEM education. To have families on board, training for parents could be organised. If families understand the value of digitalisation and STEM, they can help integrate technology, new learning methods, and approaches in schools.

The latest trends in STEM education involve new tools, methodologies, and approaches. Most of these trends are oriented towards inquiry-based learning in combination with other creative methods that promote an interdisciplinary way of teaching and learning, placing the student at the centre of the educational process. To name a few of these trends:

- **Citizen science**: This approach puts emphasis on inquiry, physical phenomena, and experimentation. Students could become citizen scientists, working either independently or with professional scientists towards a specific goal. For example, they could find ways of solving local challenges such as ecology issues or investigate issues that concern their daily life like the lack of physical activities, the food served in their school canteen, etc. They could help collect data for researchers and therefore feel more motivated to make a difference. Schools could also work together with other stakeholders like academic institutions, libraries, museums, etc.

- **Project-based learning**: It is important to make students relate to the content and what is happening in their environment. Solutions for today's problems require critical thinking,

[17] https://education.lenovo.com/us/

creativity, problem-solving, and innovation. For instance, a project could ask students to determine where an earthquake is likely to happen in their local region, look at the history of earthquakes and their impact, or examine urban plans to determine what parts of the region would be affected to present their report to the city council and discuss how the public should be informed.

- **Game-based learning**: There are many advantages that makes this approach popular among students, motivation being the key to its success. Minecraft[18]: Education Edition is a teaching and learning tool designed to support strong pedagogical practices in the learning environment. Many games are using screenless learning options (for example, classic games like Jenga or Sudoku), which help students practice 3D spatial skills.

- **Esports**[19] use students' interest in video games to engage them in school and takes advantage of it in studies and the curriculum. Esports transform the concept of a game, putting the emphasis on teamwork, where pupils can develop both their hard and soft skills (socialisation is collaboration, participation, and involvement, and when building all activities in teams, planning, and working together, improves the team working and leadership). These soft skills should also be integrated in the curriculum and school activities. Students also use digital skills because they do sound and video edits to produce tutorial videos and film matches. They also use data literacy by following player and match statistics. Moreover, they use scientific methodology to develop and test new strategies to improve their play. Although some parents and teachers are sceptical about the role of esports in education, there's a growing advocacy for well-rounded STEM education[20].

- **Coding** and **robotics** can be easily used in different subjects, integrating visual programming tools, unplugged activities, tinkering and making, and coding. There are many benefits for students such as developing computational thinking and creativity. Initiatives such as the EU Code Week bring coding and digital literacy to all students and teachers in a fun and engaging way[21].

- **Immersive learning and digital experience**: Artificial intelligence (AI), virtual and augmented reality (VR and AR), the use of digital tools, simulations, virtual laboratories, and the use of mobile phone sensors and immersive technology can provide students with new experiences, or let them visit distant science centres, cities, and natural landscapes that they would not be able to visit otherwise. Instead of passive theoretical learning, they could create

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[18] https://learn.microsoft.com/en-us/training/paths/minecraft-teacher-academy/
[19] https://www.lenovo.com/fr/fr/legion-g2/?orgRef=https%253A%252F%252Fwww.google.com%252F
[20] Esports And STEM Education: A 2020 Perspective (forbes.com)
[21] Europe Code Week

their own content. They can share this experience with other classrooms. The pandemic showed the abilities of this approach but combining real-life challenges with the digital environment should not be underestimated. For example, using Google Maps, Pendulum, Globe, or Calorimeter and stick and metre to do the Eratosthenes method to find the Earth's circumference.

- **Co-teaching**: Educators work collaboratively in a STEM classroom. This method is an inclusive practice that is increasingly used to provide the best support for students with diverse learning needs. 'Continuous dialogue between educators is needed to develop deep-collaborative skills focused on student learning' (Moorehead and Grillo, 2013).

- **Service learning** is a pedagogical methodology that tries to find how to integrate significant community service with academic content and skills, combined with critical reflection of the service learning experience. This approach has emerged as a key element in encouraging students to become active citizens and in enhancing the practical application of their studies in their local area.

- **STE(A)M**: In the first decade of the 21st century, it was suggested that arts and STEM subjects can be combined to obtain a synergic relationship with the purpose of improving creativity, engagement, and problem-solving skills (Bequette & Bequette, 2012). However, STE(A)M teaching involves incorporating not just arts, but any non-STEM subject, such as literature, foreign languages, sports, etc. Quigley, Hero, and Jamil (2017) propose a framework, where the A represents arts and humanities, that combines real-world problem-based learning, multiple discipline integration, and problem-solving skills. The Make it Open project[22] aims to put schools at the heart of their communities by enhancing collaboration between schools and local partners and by setting up projects where students learn science in real-life settings. This is interesting because this is what happens in the real research world.

Innovative approaches for future teachers

The rapid progress and development of technology brings educators face to face with many challenges concerning new skills and knowledge that they need to prepare students for their future careers and for a continuously evolving society. Universities and training services are preparing future educators' digital, pedagogical, and content skills, and there are many opportunities for upskilling and reskilling teachers on using innovative approaches in STEM education.

[22] https://makeitopen.eu/

After their initial training or degree studies, teacher training should mainly be the responsibility of teachers from the same level, since in some cases, the knowledge and experience of university teachers is far from the reality in primary and secondary schools.

For in-service teachers, there are also training programs for professional development organised by universities and international organisations, and they can also attend international exchange programs (for instance Erasmus+[23] or the Fulbright Programs[24]).

It is essential that the institutions and people in charge of teacher training have deep knowledge about the teachers' environment and working conditions including students' abilities, behaviours, available budget, space, time, etc.

Universities and teacher training centres should think about making integrated studies programmes where (future) educators could experience and see interdisciplinary and multidisciplinary approaches. Also, digital specialists should be involved to develop teachers' digital competencies. For example, Microsoft has developed the K-12 Education Transformation Framework, a guide for education leaders on navigating the complexity of transformation, envisioning what's possible, and developing a strategy to achieve it[25].

A few examples of recent technologies that can provide inspiration for innovative STEM education include innovative methods in agriculture like robots, aerial images, moisture sensors, and GPS to deal with climate change.

Inspiration can arise from a great variety of sources. For example, energy is a very relevant topic nowadays and it involves very different approaches: technical, scientific, and social. Collaboration between teachers at the same school who teach other STEM and non-STEM subjects would bring ideas and the possibility to create interdisciplinary activities.

Beyond the school itself, contextualisation in the school's local environment and students' lives could be a good place to start. Cooperation between schools and with companies and production and research centres (such as Graphene lab[26] or CERN[27]) is also very useful in the framework of comprehensive training of students in STEM education.

Other topics that can inspire STEM teachers include the use of lasers, artificial intelligence, proton therapy, antiproton therapy, or ITER[28].

[23] https://erasmus-plus.ec.europa.eu/
[24] https://www.fulbright.be/
[25] https://www.microsoft.com/en-us/education/school-leaders/k-12-microsoft-education-transformation-framework
[26] https://www.grapheneresearchlabs.com/
[27] https://home.cern/
[28] https://www.iter.org/

Challenges and opportunities

One of the main barriers[29] to innovation in STEM education teaching is the lack of time and flexibility in the school curriculum. There are many companies and initiatives designing resources and materials, but how schools can use the time available in their curricula is the real challenge and something to be addressed at policy and governmental level. Regarding professional development for teachers, educators should be able to choose opportunities based on their interests. They should also have access to conferences and teacher networks to share examples and best practices.

There are also many opportunities to bring innovation to STEM education, for example, companies can share more open materials and open their labs and facilities for teachers and students to visit them. Collaboration between all education stakeholders will help create synergies between the classroom and the real world.

It is necessary to evaluate the effectiveness of the different innovative tools and approaches in STEM education, but the evaluation should not be an extra task for already busy educators.

The industry role

Companies are constantly creating and launching the latest trends and resources for STEM education, but it is important to ensure these materials and solutions are more in line with existing curricula and students and teachers' needs. The industry contributes to bringing innovation and offers professional development opportunities for teachers. For example, Microsoft has updated their Integrated Computer Science curriculum toolkit[30], which is a great tool for teachers that want to teach and integrate Computer Science in their curricula.

Firstly, industry has a role to not only introduce innovative technology but to be able to discuss with teachers and understand their real needs. The people who apply teaching and learning methods and resources in the classroom and know the curriculum are the educators. Therefore, their feedback and collaboration can be of great assistance to companies to adapt the latest trends. Industry should also encourage educators to attend conferences.

Secondly, there is a huge set of resources everywhere, but many schools cannot afford them. The industry sector can contribute by donating equipment or developing some free tools to use in educational environments (e.g., apps for physical education, language learning, quizzes, etc.). Companies could also facilitate study visits to labs and production centres (physically, or

[29] From the STNS discussions.
[30] Microsoft's Integrated Computer Science curriculum toolkit: https://aka.ms/MSFTCS

by creating virtual visits) for secondary students to find out how things work and how products are designed. In addition, companies can collaborate in educational projects by providing knowledge and facilitating access to their resources by getting involved in educational projects (Redondas, 2020). Therefore, connections can be established between the educational world and the productive system that provides important bilateral added value.

Microsoft offers training and professional development for teachers in their Educator Center, where teachers can also stay connected with each other through the educator community[31].

How to evaluate an innovative tool or approach in STEM education

Evaluation processes are always a key part of innovation. Once a new innovative tool or approach for STEM is introduced in education, its usefulness and quality must be evaluated. Moreover, innovative tools and approaches need innovative evaluation methods.

However, these evaluation processes are a burden for teachers. In response, there is now a trend of finding tools that projects need that will be useful for teachers and students to understand how they learnt and how they implemented a new practice. There is a trend e-diaries, self-assessment tools, which are useful for both scientists and students. For instance, the System2020 project used Zine[32] as a learning portfolio method to reflect on STEAM learning during science, art, and maker workshops.

The Polar Star project[33] provided assessment for teachers and students and came back to these schools to see what worked, what didn't work, and what the challenges were. Feedback on a large scale is important for educators and students.

Microsoft has created their Transformation Assessment Tool[34] for schools to assess their needs and readiness for a digital transformation, which helps them to develop, implement, and monitor their plan for change. Carefully crafting a vision is the first step towards a successful, holistic digital transformation. This assessment asks users to indicate the current state and target state for a range of areas relevant to their education transformation journey. Users can complete as much or as little as they need to start receiving tailored recommendations. Another self-assessment tool example is the STEM School Label service under Scientix that schools can use to evaluate and better develop their STEM strategies[35].

[31] https://learn.microsoft.com/en-us/training/educator-center/
[32] https://system2020.education/resources/learning-portfolio-zines/
[33] https://polar-star.ea.gr/
[34] https://edujourney.microsoft.com/k-12/education-transformation-assessment-tool/
[35] https://www.stemschoollabel.eu/

The tools cannot simply be used to 'tick' what they have learnt but encourage reflection on their own practices. Evaluation methods such as portfolios, self-assessment, peer-assessment, and rubrics with very specific criteria and objectives are useful methods that should be combined in the classroom. Evaluation processes must be implemented and addressed to students and teachers to reflect on what can be improved.

Professional development and innovation

To help teachers use new methods efficiently in their STEM classroom, professional development is needed. There are big differences among countries in Europe, therefore it is not only a matter of individual and school choices, but also political investment and decision-making at high level. In some countries, teachers are left alone, as the COVID-19 pandemic showed. This must be dealt with and tackled at a high political level and there should be a lobby of people working in formal education to promote teachers' development and make sure teachers are better valued and promoted in their careers and professional lives.

In Spain, teacher training focuses on traditional on-site or online courses, but teachers should have assistance when participating in professional meetings and conferences and new networks must be promoted more efficiently. Seeing a colleague who is performing an activity and collaborating with other participants in real life promotes this exchange of experiences among teachers. The world of conferences is very common among universities and research centres, but innovation and research should be promoted among teachers too. For instance, Scientix held their 4th conference online on 18 and 19 November 2022[36]. Teachers should be, above all, lifelong learners. Gaining new knowledge and applying new methods in their teaching will help them understand if it works, how it works, and what alterations should be made to make it more effective. Therefore, professional development focused on innovation for STEM should:

1. Promote educational and pedagogical research and **innovation in schools**, meaning that research should be done by teachers, not only by external experts, because they know the educational conditions including time, space, available materials, and students' usual reactions.

2. Put more effort into teacher training and collaboration; not only courses, but also **professional meetings and networks** in particular. Conferences remain a field that need to be further explored by teachers at pre-university levels.

[36] http://www.scientix.eu/conference/

For JA Europe, professional development for teachers is key and they integrate teacher training with professionals from the business sector. They also give students the opportunity to meet business partners – not only academic ones, but also practical and real-life examples. Business mentors train teachers in STEM and career-related content. Professional development can be useful if there is practical example of how STEM can support them in their career and future development.

Microsoft's Leaders in Digital Transformation of Education[37] programme brings together education leaders to accelerate the achievement of their education transformation goals using a scalable, sustainable, and locally empowering approach.

Professional development should also be a matter of choice, not an obligation. In Serbia, teachers must attend several pedagogical or practical or professional courses to keep their job and renew their licence, but this becomes meaningless. The teachers go to the programme because it is compulsory, not because they want to. Professional development should always insist on continually monitoring the programmes' outcomes. For example, the LUMA Centre in Finland[38] establishes a continue collaboration with teachers.

STEM and STE(A)M activities to address all subjects

How can we design and implement interdisciplinary STEM and STE(A)M activities that address all subjects equally? Interdisciplinary approaches are the pending matter in education as they should be integrated in the classroom (1) very carefully, not obligating teachers to teach subjects in which they are not experts, (2) through collaboration, in the framework of projects, and (3) involving not only different subjects, but several schools, external institutions, the wider community, etc.

To create and implement interdisciplinary STEM and STE(A)M activities for all subjects equally, it is essential to make connections between different subjects and how we can combine them. Moreover, the project-based learning and the collaborative learning approaches could be of great help in this direction. We can also collaborate with educators who teach other STEM and non-STEM subjects to share ideas and collaborate on interdisciplinary activities.

STEM disciplines can benefit from non-STEM subjects as they connect disciplines in ways that are motivating students (Henriksen, 2014)[39]. For example, students can make art projects

[37] https://www.microsoft.com/en-gb/education/ldte
[38] https://www.luma.fi/en/
[39] https://pdfs.semanticscholar.org/420d/a29154558053592dcd30ba747f715cddf816.pdf

using coding, electronics[40], trigonometry, or video animation software. Similarly, presenting scientific evidence to an audience taps into language and communication.

A challenge to integrating a non-STEM subject is to not allow the (A) to be ignored while the activity focuses on STEM, or vice-versa. A project about making and designing sweets should not omit a discussion about the chemical processes that affect the texture of sweets, or while painting an engineering project, students should also reflect on their choice of colour and design. Although STE(A)M teaching is considered to develop creativity and problem-solving skills, measuring these skills is challenging (Perignat & Katz-Buonincontro, 2019)[41].

Non-formal learning and outreach

Non-formal learning refers to learning that occurs away from a structured, formal classroom environment. Informal learning methods adopt Dewey's idea of experiential learning, suggesting that knowledge should be constructed through real-life experiences (Grady, 2003). Students spend a substantial proportion of their time outside of school with their friends and family. Learning does not end after school because they also encounter or learn about real-world problems outside of school.

Non-formal STEM learning programmes, such as summer camps for robotics or project competitions for solving community problems, can engage disadvantaged students and encourage peer learning and mentoring activities (Denson et al. 2015). For example, between 2010 and 2014, the Serbian Physical Society organised many science festivals, and the number of students that entered, particularly in physics, was beyond expectation. One weekly exhibition dedicated to CERN took place in the Sveti Sava High School in Kladovo.

Competitions and local events also make STEM visible in public news. One challenge of non-formal learning settings is that it can be more difficult to evaluate their impact because they do not take place in a school setting but rather in science centres or at science festivals (Allen & Peterman, 2019), for example. However, learning moments can be as simple as a discussion between families and children about the tides by the seaside while they are on holiday by the coast.

Big picture education (BPE) can also be considered as an outreach model, as, in this concept, adult mentors from outside the school are involved. Hogan and Down (2015) think that BPE might be the response for the lack of interest in STEM subjects. If the aim is for more young people to take an interest in STEM subjects, the current curricula, pedagogy, relationships,

[40] https://www.tandfonline.com/doi/abs/10.1080/00043125.2016.1176492
[41] https://www.sciencedirect.com/science/article/abs/pii/S1871187118302190

community, and interests must be re-evaluated. With BPE, the focus of the learning must be on the student's interests and needs, which implies that the curriculum must be relevant and allow the students to do real work outside the classroom. For this, they need mentors outside the school that share their interests and can thus support their learning. With BPE, students' development and abilities are measured by the quality of their work, considering the way that their work has helped change them. BPE is holistic and prepares students for all areas of life, not only focusing on profound knowledge but also on transferable skills such as teamwork and creative work.

Makerspaces also have the potential to be an outreach model. A makerspace is a collaborative workspace inside a school or other public or private facility where children, adults, and entrepreneurs can make things, learn, and explore. Sometimes, they use technology such as 3D printers, laser soldering irons, etc. or simply do workshops where they can do woodwork, build blocks, or explore with art supplies such as cardboard. The idea behind makerspaces is that learners have a maker mindset and create something out of nothing. These spaces often help to prepare those who need 21st century skills in the field of STEM. Tan (2022) points out that makerspaces are an innovative way to teach STEM, as social and material aspects of knowledge are also important, and since understanding scientific knowledge requires the students to know more than the abstract concepts typically presented in schools. In makerspaces, teachers are likely to lean towards activities that have a high degree of engagement and therefore, students are not only prepared for work but also for participating in socio-political activities.

Future directions for innovative STEM teaching

Whether it is technology-supported innovation, an outreach programme, STE(A)M or any other methodology, a pedagogy-driven approach should be prioritised according to the UNESCO's World Education Forum (2015).

Investing in innovative STEM education is crucial for the development of future leaders and innovators in different fields. Bringing innovation to schools is not always easy, but collaboration between teachers, industry, and other networks facilitates exchanges that build, share, and scale good and innovative pedagogical practices.

Bridging the digital divide

The lack of access to, and skills for, innovative education technology cause technological inequalities that need to be solved, along with gender inequalities in STEM fields. To close the gaps and bring innovation to education, all stakeholders need to facilitate interaction and create opportunities to provide the technology that will be needed to empower teachers.

JA Europe calls how fast education and technology are evolving a 'canyon'. For example, how young people want to become YouTubers because they enjoy watching video-based online content rather than classical broadcasting television[42]. There is a need for professional development for teachers to take over this technology and virtual world. Educators need training on new technologies and new digital tools, so they are able to teach them effectively to their students.

Some great resources on how to explore citizen science for teachers have been created by SEEDS[43]. And for French speakers, there are materials available for educators to introduce physics with a smartphone in the classroom[44].

When schools do not have enough technological resources, there are some low-cost opportunities such as bringing students to the nearest institute, museum, hospital, makerspace, or hi-tech company. Schools could also find sponsors for more cost-demanding activities (such as CERN or Ars Electronica Center) or use available video-based content (such as Institute for Human Anatomy[45]or Operation Ouch[46] to learn about anatomy).

Another solution for bringing innovation to schools is borrowing materials. The LUMA[47] centre lends out equipment and uses postal services to send them anywhere in Finland. A teacher can borrow equipment to study the quality of water in the many lakes and rivers in Finland. Equipment is mobile most of the time and go from school to school. The National Cancer Institute of Serbia[48] also allows schools to use materials.

The lack of equipment and access to it are big challenges in education. Therefore, open-source educational resources can be a great way to find and apply new and innovative resources such as using scientific apps like FizziQ[49] or Physics Toolbox Sensor Suite[50] involving sound, light, movement, etc. Sometimes, expensive equipment is not needed in science. Imagination,

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[42] https://www.emerald.com/insight/content/doi/10.1108/YC-10-2020-1231/full/html
[43] https://eu-citizen.science/blog/2022/03/28/how-empower-teenagers-health-issues-practical-guide-teachers/
[44] https://hebergement.universite-paris-saclay.fr/supraconductivite/projet/smartphone/
[45] https://instituteofhumananatomy.com/
[46] https://www.youtube.com/c/OperationOuch
[47] https://www.luma.fi/en/centre/
[48] https://www.ncrc.ac.rs/?fbclid=IwAR1nqbsOAR-5l66CGeYqBuoYQGouSnl-SesetYjvdswxMpv6amj7Ml-p5uc
[49] https://en.fizziq.org/
[50] https://play.google.com/store/apps/details?id=com.chrystianvieyra.physicstoolboxsuite&hl=es_419&gl=US&pli=1

resources, and asking students what we can do with domestic materials can spark the beginning of a project. Citizen science is a powerful way to gain new experiences, as can be seen in the SEEDS science blogs[51].

There are also many organisations offering virtual tours for students of all levels and backgrounds. For example, the winter and summer schools of the FRONTIERS project[52] offered virtual tours at CERN and the European Gravitational Observatory (EGO)[53]. There are also many funds and grants that schools can apply for to buy equipment for their laboratories. In Finland, the Lukema network[54], an open community for all high school teachers and principals interested in developing mathematics and sciences, has also designed virtual labs and visits. By removing these digital barriers, teachers can focus on education.

Partnerships to organise outreach programmes

Education authorities and policy makers can help schools and teacher training institutions organise outreach programmes, but it is important to carve out time in the curriculum to allow for these activities.

When it comes to outreach programmes for schools, there is a need for the curriculum to be more flexible and allow time for these activities to be implemented. For example, allowing young people to shadow business professionals. If educational authorities create a flexible system that allows for opportunities, more outreach programmes can be put into place and scale more.

For instance, the Flemish STEM platform,[55] where students connect with companies to raise their interest in a specific career. People from companies can share their experience and this has had an impact on the motivation and real knowledge of students. As they were talking about their jobs, it increased students' interest in these jobs. The same initiative exists in France supported by the Ministry of Education, where they have two kinds of outreach programmes[56] where 1) university teachers help primary school educators, and 2) teachers go for in-service training with companies. The STE(A)M IT project also created a career advisers' network[57] with a repository of STEM job profiles[58].

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51 https://eu-citizen.science/blog/2022/01/24/citizen-science-powerful-way-new-learning-experiences/
52 https://www.frontier-project.eu/
53 https://home.cern/news/news/cern/five-schools-virtual-visit-cern-and-icecube
54 https://www.lukemaverkosto.fi/briefly-in-english/
55 STEM-platform en -stuurgroep (vlaanderen.be)
56 https://fondation-lamap.org/
57 https://steamit.eun.org/career-advisers-network/
58 https://steamit.eun.org/category/stem-careers/

JA Europe promotes entrepreneurship and job orienteering for young people. They develop different programmes and projects worldwide with the objective of encouraging entrepreneurship in students before finishing their compulsory education[59].

The 'Schools As Living Labs' EU project held several workshops with policymakers in education and the results show that there is a need to scale up from successful individual classroom-level initiatives. This process takes time and effort and requires more autonomy for teachers, like a possibility for a flexible curriculum and support for an evaluation framework. This project opened a public consultation to develop a set of policy recommendations and mainstream the open-schooling education approach[60].

The European Children's Universities Network[61], born in the '90s, is another example of where citizen science and open schooling is done together in the same level of schools' outreach activities for universities nearby, offering activities and contacts.

Capacity building for innovative STEM educators

When focusing on teacher training, education authorities must encourage educators to participate in networking events with colleagues. There are plenty of courses available where experts teach the teachers, but it is even more important to see what other colleagues are doing in other schools. STEM educators are implementing innovative approaches in their classes, but the lack of networking opportunities and time hinders the possibility of scaling up the good results. To facilitate these networking opportunities, education authorities and policy makers should:

1. Focus teacher training on more proactive activities with other stakeholders at different levels: local, regional, and international.

2. Facilitate professional meetings, networks, and collaboration between teachers. It takes extra effort for teachers to participate in conferences, therefore there must be a good reason for them to be a part of networking activities.

3. Promote educational and pedagogical research and innovation in schools. By organising quality programmes, supporting teachers' development programmes, and staying by the schools' side, as the StarT-programme from the LUMA Centre is doing in Finland[62].

[59] http://www.jaeurope.org/education/ja-programmes.html
[60] https://roadmap.schoolsaslivinglabs.eu/
[61] https://eucu.net/
[62] https://start.luma.fi/en/

How schools can integrate the most appropriate trends

There are many tools and solutions available for schools, and it is the overwhelming offer, along with educators' lack of time and strict curriculums, that makes it difficult for schools to choose the most appropriate trends for them. One practical solution is that education authorities fund certain upper secondary schools to become 'national developers'. These schools develop and design materials and arrange in-service training. Therefore, there is 'someone' who does the work for everyone. It has been noticed that teachers do not use the material if it is not readymade[63], and it is also proven that they prefer the system where the other educators that have created or used the materials earlier guide them on how to use it[64].

In Flanders, online tools are being voted for by people from the ministry and teachers are being told which level this material is good for etc. Someone is looking at the materials and if it's useful and for which level[65].

Conclusion

Whether it is technology-supported innovation, an outreach programme, STE(A)M, or any other methodology, a pedagogy-driven approach should be prioritised. Technology-supported innovations can only become relevant, meaningful, and sustainable if they provide efficient and convenient solutions to real educational needs. This is not only true for technology but also for all other innovative approaches.

Technology takes on an important role in all areas of life, and 21st century skills and competences such as teamwork, creativity, and problem-solving skills are becoming increasingly important in a diversified and multicultural world. Innovative STEM education should be able to facilitate learning experiences linked to the world around us. Consequently, students will not only be more motivated to take on STEM subjects, but they will also enhance their creativity and thus their higher-order thinking skills.

Beyond tools and approaches, the next steps for schools to innovate in STEM education is to address the time they have in a different way. The biggest barriers to implementing STEM innovative practices are the time and flexibility to implement all these new approaches. The challenge is not integrating innovation into the existing curriculum, but the lack of time to do it.

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[63] https://grattan.edu.au/wp-content/uploads/2022/01/Making-time-for-great-teaching-how-better-government-policy-can-help-Grattan-Report.pdf
[64] https://www.journals.uchicago.edu/doi/epdf/10.1086/711012
[65] https://www.klascement.net/

Science has changed rapidly, not only because of constant new discoveries, but also because it has changed in its methodologies, from science based on authority to science based on participation, from science based on stable results to science based on complexity and uncertainty. The usual method in traditional education is linear and must deliver quantitative results. But the world is much more complex and uncertain. It’s crucial that schools evaluate their capacity to deal with uncertainty, as they did during the COVID-19 emergency. This will bring schools back to the centre of innovation, where the curriculum is flexible and equips students to deal with new challenges.

Acknowledgements

This paper is part of the Scientix observatory series. Scientix, the community for science and mathematics education in Europe, initiated by the European Commission (Research and Innovation DG), has set up the Scientix Observatory to help the development and dissemination of different science education projects and document good practices in various aspects of STEM education. The Observatory provides short summary articles focused on one or several related themes or initiatives, or the state of play of different topics related to science education (http://www.scientix.eu/observatory).

The work presented in this document has received funding from the European Union's H2020 research and innovation programme – project Scientix 4 (Grant agreement N. 730009), coordinated by European Schoolnet (EUN). The content of the document is the sole responsibility of the organisers and the authors. It does not represent the opinion of the European Commission (EC), and the EC is not responsible for any use that might be made of information contained.

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