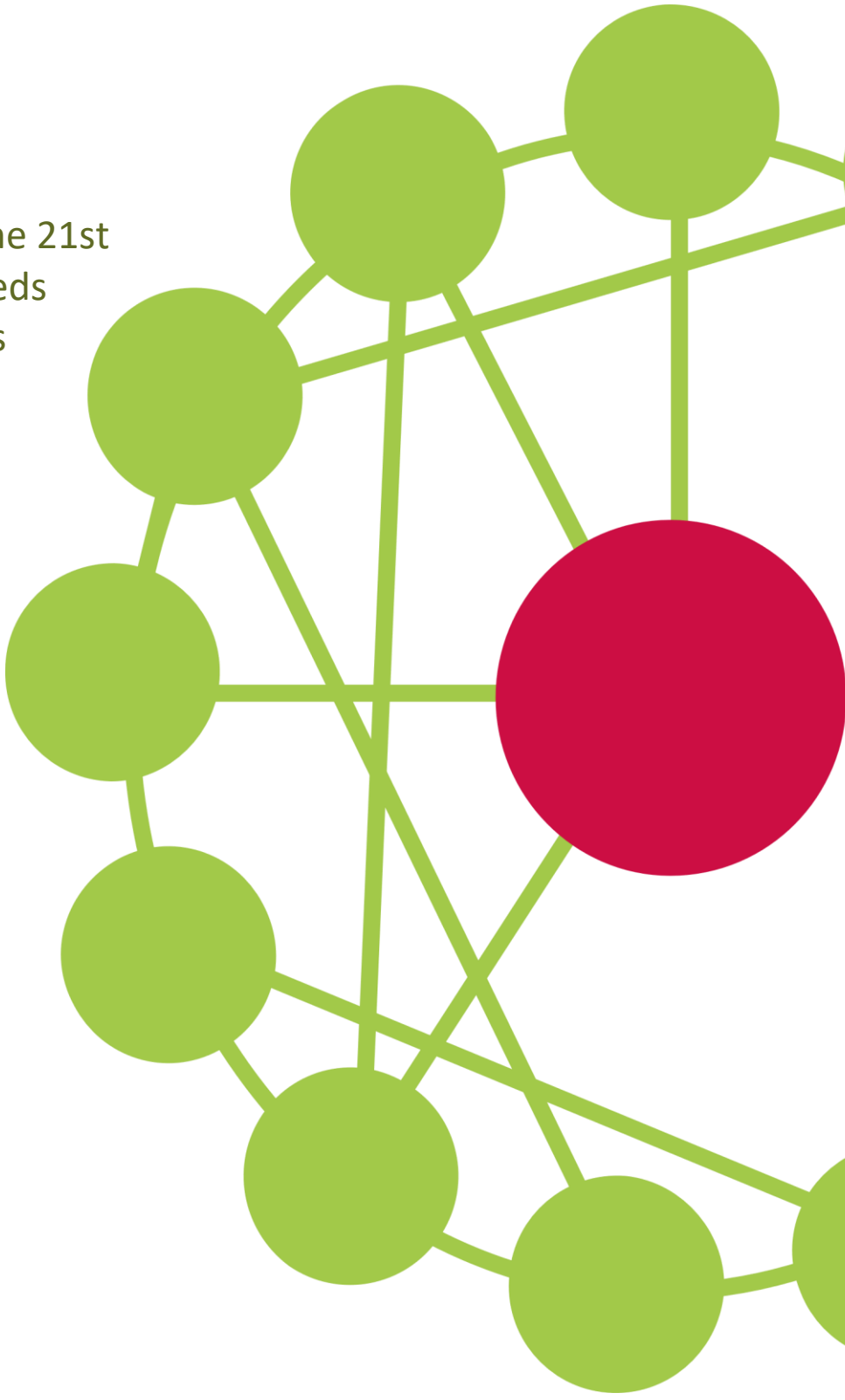
SUPPORTING STEM TEACHERS

STEM education for the 21st century: Features, needs and support measures



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International Centre for STEM Education

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Contact Information
Coordinating Institution: University of Education Freiburg, International Centre for STEM Education
(ICSE) Coordinator: Prof. Dr. Katja Maaß
Project Manager: Anna Boelke, anna.boelke@ph-freiburg.de
Lead partner for this document: EDEX/UNIC
Authors of Policy Brief 2. Evi Konstantinidou and Maria Evagorou, UNIC
Website: https://icse.eu/teacher-academy/

ICSE Academy Project Consortium
Charles University (CUNI)
Constantine the Philosopher University (CPU)
Educational Excellence Corporation Limited (EDEX)
Hacettepe University (HU)
Jönköping University (JU)
Klagenfurt University (KLU)
National and Kapodistrian University of Athens (NKUA)
Norwegian University of Science and Technology (NTNU)
University of Education Freiburg-International Centre for STEM
Education (ICSE)
University of Jaèn (UJA)
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Vilnius University (VU)

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DISSEMINATION LEVEL	
X	PU=Public
	PP=Restricted to other program participants (including the EC)
	RE=Restricted to a group specified by the consortium (including the EC)
	CO=Confidential, only for members of the consortium

TABLE OF CONTENTS

Excecutive summary

This comprehensive policy report explores the landscape of STEM education. It outlines features of up-to-date 21st STEM education and based on this describes requirement for a related teacher education and professional developed. Balancing these requirements with constrains for teachers, it comes up with recommendations for professional development providers and educational policy makers and drivers. With a focus on in-service and pre-service teachers across participating countries, the report aims to provide information about the multifaceted challenges and opportunities in advancing STEM education through targeted professional development initiatives. It is based on in-depth group discussions in 13 countries as well as questionnaires completed in 13 countries.

This report was developed within the Teacher Academy called ICSE Academy (proSTEM; 2022-2025) funded by the Erasmus+ programme.

The report was written considering the background of a serious underarchivement in STEM subjects, a limited interest in STEM careers, especially with girls, which all leads to serious recruitment difficulties in relation to STEM careers and especially for STEM teachers.

In the light of this background situation we sought to answer the following questions:

(1) What STEM education do we need to improve students' performance, raise their interest in science careers, combat gender disparities and enable them for active citizenship in the technology and information driven 21st century?

(2) What kind of teacher education and professional development do we need to foster such a STEM education?

(3) Which needs do teachers has when intending to evolve their teaching?

(4) How can we support teachers in evolving their teaching given the constraints?

Important aspects of an up-to-date STEM education, suitable for raising students' performance and their interest in STEM and STEM careers and enabling them to live in the 21st century in the sense of active citzenship are:

- Connecting STEM with Real Life
- Giving students access to research opportunities
- Addressing interdisciplinary questions and problems
- Outlining possible STEM careers
- Changing Perceptions about STEM
- Addressing Gender disparities
- Keeping up with technological advancements
- Clarifying the possibilities and limitations of STEM in democratic decision–making
- Incorporation of Entrepreneurship

If all these aspects are supposed to be included in STEM education, teachers need to educated accordingly and need time to explore new aspects of teaching. However teacher suffer from enormous time constraints and a lack of materials. To support teachers in overcoming these constraints, we suggest a variety of support measures, such as

- Provision of high-quality teaching material in data bases
- Provision of lesson examples
- Offering PD courses in a variety of forms
- Offering innovative student-teacher-workshops as best-practice teaching

- Attract teachers with European PD activities
- Support collaboration among teachers
- Offer high-quality and choherent pre- and in-service education
- Incentivizing interdisciplinary STEM education at schools
- Integration of technology
- Offer more national-Level training
- Development of an up-to-date STEM curriculum
- Change Assessment Practices
- Appreciating the performance of teachers in school

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Introduction

This comprehensive policy aims do describe the actual challenges and possibilities in STEM education in Europe and based on the results of a survey for policy makers and experts. data collection process employed a multi-faceted approach, combining questionnaire surveys and in-depth group discussions. The group discussions were held in each of the 13 partner countries of the ICSE Academy. In each of the partner countries a National Policy Committee was set up, comprising at least 4, mostly more, policy makers and drivers, who advise the project partners on the country level. These policy makers and drivers work closely together with teachers and on the other hand are involved in policy making and therefore provided a broad picture of what needs to be done. Further more a questionnaire was sent out to STEM education stakeholders and teachers in all thirteen countries. This methodological approach ensured a comprehensive understanding of stakeholders' perspectives on STEM education and professional development needs.

In the following we will first give some information of the project in which the study was conducted, the ICSE Academy, and outline the background of the study, before we turn to the results obtained.

The ICSE Academy

The ICSE Academy (proSTEM) is a European Teacher Academy funded by the Erasmus+ Programme (2022 – 2025). The ICSE Academy supports the EU's endeavours to minimize the amount of low-performing STEM (science, maths, technology, and engineering) learners. It does so by investing in a new era of a high-quality STEM teacher workforce by innovating teacher education based on existing best practices and transnational exchange strategies. This approach draws on mobility and collaboration as an integral part, thereby supporting young and established STEM teachers across Europe.

Relevant features of the ICSE Academy are, in a nutshell:

• High-capacity partnership: The ICSE Academy partners are experienced higher education researchers, STEM initial teacher education (ITE) and continuous professional development (PD) providers, educational policy makers, and schools from 13 countries learning with, from and about each other through specific innovative collaborative structures.

• A professional learning concept with three innovative professional learning formats for pre- and in-service STEM teachers, achieving effectiveness, accessibility and transferability to all Member States and fostering European mobility and collaboration:

- Peer-learning through job-shadowing (ITE/CPD providers attend each other's courses to learn from each other)
- Interdisciplinary European workshop series (for teachers across Europe, run jointly by all ITE/CPD providers)
- Collaborative European summer schools (in NL/CZ with focus on collaboration between participants as well as organizers)

• Distinct needs-feasibility-alignment: The development of our professional learning formats is needs-driven in two ways: (1) Teachers will communicate bottom-up what they need and (2) policy makers will communicate top-down requirements from the policy level.

The ICSE Academy will use a systematic approach to inform national and European policy based on a profound policy needs analysis. It will include targeted dissemination/communication and institutionalized exchange structures (e.g. Policy Round Tables).

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Background of the report

One major challenge for Europe's education systems is: More than 20% of 15-year-olds cannot complete simple tasks in science and maths (COM 2020a). The Trends in International Mathematics and Science Study (TIMSS) affirms this deficit, stating that more than 20% of Europe's pupils are in the lowest maths and science performance level and not even 10% achieve the highest performance level (Mullis et al. 2020). This underachievement in STEM subjects is a serious threat to Europe's innovation-dependent competitiveness in our changing, technological, and ecologically endangered world.

A further challenge for Europe's education system is that STEM education does not lead to a sufficient number of young people being interested in STEM careers (Archer et al. 2013). Most of the students are not aware of careers science can lead to, the brainy image of scientists and science careers as well as the view that scientists are mainly white, middle-class hinder young people of pursuing STEM careers (Archer et al. 2013).

This situation leads to serious recruitment difficulties in relation to STEM careers in a large majority of European countries (STEM Alliance 2017). These recruitment difficulties are sharpened by large gender disparities (Großkopf & Weiiß 2019). Reasons for these gender disparities are stereotypes about women in STEM careers (technical subjects are considered as not being female), wrong opinions about performance of women in STEM educations (Women cannot do science) as opposed to the results of PISA (see OECD 2016), a strong gender bias, a lower self-efficacy of women in relation to STEM as well as unfortunate attribution pattern in relation to success in STEM (e.g. I was lucky instead of I know STEM), as well as the fact that women prefer jobs that have a social components and do not know what social components STEM jobs can have (Stemmann 2021, Roper 2019, OECD 2016, Alam & Tapia 2020, Hahnel & Stemmann 2023, Hill, Corbet & Rose 2010, Eccles 2007).

The recruitment difficulties in relation to STEM careers also influence the STEM teacher workforce. Around half of the Member States suffer from a lack of high-qualified STEM teaching staff (COM/EACEA/Eurydice 2018) or will do so in the next decade.

Also, many teachers – both pre- and in-service – do not have the competences they need to teach in today's high-demand education systems with challenges such as climate neutrality, gender gaps, heterogeneity, and digital learning tools (ET2020 2015). However, teachers are the cornerstones (Council of the EU 2020) and so this is a severe threat, as up to three quarters on student achievement can be explained by teacher effects (Rivkin, Hanushek & Kain 2005). Consequently, there is a need for initiatives which support STEM teachers in developing high-quality teaching competences.

Guiding questions

In the light of this background situation we sought to answer the following questions:

(1) What STEM education do we need to improve students' performance, raise their interest in science careers, combat gender disparities and enable them for active citizenship in the technology and information driven 21st century?

(2) What kind of teacher education and professional development do we need to foster such a STEM education?

(3) Which needs do teachers has when intending to evolve their teaching?

(4) How can we support teachers in evolving their teaching given the constraints?

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We will address these questions in the following by outlining what the policy makers and drivers emphasized in the group discussions and in the questionnaires.

(1) STEM education

An up-to-date STEM education which improves students' performance, raises their interest in science careers, combats gender disparities and enables them for active citizenship in the technology and information driven 21st century, should have the following features:

Connecting STEM with Real Life

In STEM education students should see the relevance of STEM subjects for their personal life and for society. They need to learn how STEM subjects can be used in life. To effectively connect STEM education with real life, it is important to emphasize authentic applications of STEM disciplines. Implementing open schooling (projects in which students work together with community members to solve real existing community problems) can facilitate this connection.

Giving students access to research opportunities

Giving students access to research opportunities can enhance students' curiosity and drive for learning in STEM fields. This can be done by using the concepts of inquiry-based learning and teaching and problem-solving. Open schooling projects also offer this possibility when working on community problems.

Addressing interdisciplinary questions and problems

Whilst most of the real-life problems are interdisciplinary by nature, STEM education at schools is often still separated into mathematics, biology, physics and chemistry, with technology and engineering often being neglected. To prepare students for life, interdisciplinary STEM problems should be addressed.

Outlining possible STEM careers

As many young people do not know what kind of different STEM careers exists, it is vital to outline different STEM careers, either by using tasks with contexts from different STEM careers or by informing about STEM related careers, possibly in cooperation with enterprises which might be willing to send role models to schools (thereby combatting the stereotype of white middle class men) or doing guided tours.

Changing Perceptions about STEM

Promoting a more inclusive and positive perception of STEM will encourage broader participation and appreciation, helping to break down barriers and foster a more diverse and dynamic STEM community. Changing perceptions about STEM requires a multi-faceted approach. It is essential to address negative perceptions of STEM subjects, such as the widespread view of mathematics as inherently difficult. This involves challenging the simplistic categorization of individuals as either technical or non-technical, which can limit their potential and interest in STEM fields.

Addressing Gender disparities

Addressing gender disparities in STEM education is crucial, as there is a significant underrepresentation of women and girls in STEM studies and STEM careers as was outlined above. To achieve this, teachers need to be prepared to combat such gender stereotypes as outlined above, emphasize girls STEM competences in lessons and contradict their attribution patterns and outline social components in STEM related careers.

Keeping up with technological advancements

As technological advancements in STEM will shape our future lives and also those of the students, it is impediment to include these developments, in particular AI, in STEM education. For example, most of the Physics dealt with in lessons dates from the 19 century or before. Whilst is of great importance of

learning about these essentials it is also great importance of preparing students of how to deal with current developments in the sense of active citizenship.

Clarifying the possibilities and limitations of STEM in democratic decision–making

In times of disinformation it is indispensable to show which role STEM can play in democratic decision-making. Often decisions on how to deal with problems that are relevant for society are based on STEM but are also influenced by other aspects (such as ethical, economic or political aspects) and students need to learn how STEM and other aspects come together in such issues, so-called socio-scientific issues (SSI). Also it is important that students can identify a line of arguments as scientific or non-scientific.

Incorporation of Entrepreneurship

Integrating entrepreneurship into STEM education is crucial for empowering students' technical skills and the innovative mindset necessary for effective problem-solving. By combining entrepreneurship with STEM teaching, students are better prepared to translate their technical knowledge into real-world solutions and entrepreneurial ventures, driving future innovation and economic growth.

(2) STEM teacher education

With such ambitious STEM education in mind, of course teacher education and professional development courses need to prepare teachers for such a way of teaching.

Need for programmes fokussed on pedagogical content knowledge

There is a pressing need for comprehensive professional development programs that not only enhance teachers' subject matter expertise but also focus on acquiring essential pedagogical skills and pedagogical content knowledge. In this context here this refers particularly to real-life contexts, inquiry-based learning, problem-based learning, open schooling, interdisciplinary teaching and socio-scientific issues.

Learning about STEM careers

There is a huge variety of STEM related careers. This is not easy for teachers do to their own education which is in most cases restricted to school, then university and then again school. Therefore professional development courses need to pick up this issue, by providing information on STEM related careers and tasks with real-life contexts taken from professions.
→ Here PD provider can cooperate with enterprises, who can provide role models, real-life contexts for texts or guided tours through their enterprises.

Learning about perceptions and gender disparities

To enable teachers to change students perceptions and to overcome gender disparities, teachers must be made aware of them and learn ways how to overcome them.
→ This should be done in each professional development course as a cross-cutting topic as well as in specific courses targeting these topics as a main topic.

Learning to use AI in and for teaching

When teachers are expected to include technological advancements like AI into teaching, they need to learn about these advancements themselves. In relation to AI they need to learn (1) how they can support their students to learn about AI and (2) how teachers themselve can use AI for teaching.

AI facilitates learning by aiding in coding and programming, providing error identification, and offering personalized guidance to students. Additionally, AI contributes to the development of virtual labs and simulations, enhancing hands-on learning experiences.

Entrepreneurship in STEM education

Entrepreneurship describes the process of creating, developing and managing a new business or project with the aim of turning

innovative ideas into reality. It goes beyond the mere starting of a business to include the ability to drive innovative change within existing organizations that leads to growth and progress. For many teachers this is not connected to STEM education. Naturally, if they are supposed to include this in their STEM education, this must be included in their teacher education and in professional development.

Taken together, this puts high demands on STEM teacher education as well as on professional development courses. And last but not least, it would put high demands on STEM teachers who would have to attend all the courses. Consequently, now we step back from these high ambitions and have a look at teachers' constraints.

(3) Teachers' needs

Time constraints of teachers

The profession of teachers has changed. Teachers cannot simply concentrate on the subject they are teaching, but they have attend to more and more other tasks. They have more educational duties than in earlier days, more organisational tasks, more multi-lingual students and more social conflicts to deal with. This reduces the time on tasks significantly. Furthermore, curricula and assessment traditions leave but little room for additional content like e.g. socio-scientific issues or AI in STEM education. The high workload in preparing lessons, correcting assignments and talking to parents does not leave much time for additional professional development courses. Consequently offers for professional development must take the high workload of teachers into account.

Insufficient resourses

Teachers face significant challenges due insufficient resources for effectively covering STEM subjects. Many textbooks do not offer possibilities for teaching in a way like outlined above in part (1). However, good teaching materials are a necessary precondition for teachers to implement a certain teaching approach.

Consequently, if teachers take the time to attend a professional development, it is essential to provide good materials, ready for direct use in class, so as to relieve teachers from their high workload.

Professional development for direct use in class

Given their high workload, teachers always ask for very tangible professional development with ready-to-use materials, so that they can go back to school and almost directly use them.

(4) Support measures for teachers

Comparing the needs and constraints on the side of the teachers with needs in STEM teacher education and professional development, it becomes very clear, that immediate change is not possible.

Still, in view of the urgent need of making STEM education fit for the 21st century and raising students's performance, as well as their interest in STEM and STEM careers and making them see the relevance of STEM for their life, there is an urgent need to support teachers.

In the following we will list support measures that came out of our discussions and questionnaires. We start with measures that can be iinitiated by teacher education and PD providers. The further down a measure is in this list, the more support from educational policy is needed.

High-quality teaching material

High-quality teaching materials are paramount for effective STEM education. Utilizing up-to-date and relevant materials keeps the curriculum aligned with current developments in STEM fields, enhancing the learning experience. Tailoring worksheets to specific educational levels ensures that lessons are

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appropriately challenging and accessible. Increasing the provision of exercises fosters active learning and mastery of concepts. Furthermore, promoting the practical application of content encourages students to see the real-world relevance of their studies, preparing them for future STEM careers and challenges.

Provision of Lesson Examples

The provision of lesson examples is essential for enhancing STEM education. These resources offer a variety of materials and adaptable resources for classroom use, aiding teachers in effectively delivering STEM content. Additionally, the sharing of STEM practices and project stories through these examples facilitates discourse among teachers, promoting the exchange of innovative ideas and effective teaching strategies. This collaborative approach facilitates continuous improvement and enrichment of STEM education practices.

→ Data bases that provide teachers with classroom materials, lesson examples and information on pedagogical approaches are pivotal in this respect. It is important to note that these data bases should not only provide standard tasks and exercises but also include materials on approaches as discussed under (1). One example of such a data base is data base developed within the ICSE Academy https://icse.eu/icse-academy/materials/.

Offering PD courses in a variety of forms

As outlined below, teachers suffer from a high workload and time constraints.

→ To meet teachers' needs in relation to time, PD courses should be offered in a variety of forms. This relates (1) to the length of the course. Due to the little time available, PD courses should be short-time (one-off) courses of about 2-3 hours, otherwise only little teachers will apply. However, as we know from research, that these courses have less impact on teachers than long-term courses, we suggest to offer modular course, so that teachers can participate on more than one course but do not have to. (2) this relates to the mode of the course: it attracts different teachers if you offer the course both face-to-face and online.

Offering innovative student-teacher-workshops

We have repeatedly refered to the time constraints of teachers. One means to attract teachers to further professional development is offering innovative student-teacher-workshops. These workshops are tailored to students (e.g. a workshop on AI or on socio-scientific issues) but their teachers are also allowed to participate. This is of added value for teachers as they are relieved of time (as they do not have to prepare the lesson) and also see new ways of teaching as a best example. This has proven effective with some the partners of the ICSE Academy.

Added value of European PD activities

One the one hand, European PD activities are difficult for some teachers due to language issues, on the other hand the offer an added value for pre- and in-service teachers, due to the possibilities to exchange with teachers from other countries and learn about other perspectives on teaching.

→ Our online European Workshop series, held by various teacher educators from the ICSE Academy attracted many participants from the 13 partner countries.

Collaboration among Teachers

Collaboration among teachers is crucial for advancing STEM education. Small group settings provide an ideal environment for meaningful collaboration, allowing teachers to exchange ideas, discuss exercise and assignment results, and collectively refine teaching approaches.

→ Collaboration among teachers can also be initiated in professional learning activities. In the Workshop series of the ICSE Academy as well as in the ICSE Academy summer schools

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group work among teachers is core to our proceeding, and is often continued over a longer period of time (e.g. several weeks in the workshop series).

Leveraging online communities further enhances knowledge exchange by enabling to share resources, best practices, and innovative teaching methods across geographical boundaries. Empowering educators through collaborative professional development initiatives strengthens their skills and knowledge base, ultimately enhancing their ability to deliver high-quality STEM education that prepares students for future challenges in STEM field.

→ Educational policy can support cooperation by offering cooperation spaces at school (rooms and timeslots), by setting up cooperation teams and by initiating team teaching.

New impulses to STEM education need to be included in pre-service and in-service education

Considering what is needed in up-to-date STEM teaching (see 1) the topics at hand should be included in both pre- and in-service education. To develop a teacher education coherent with professional development, providers of teacher education and professional development providers need to cooperate. This should be initiated both by the providers on the local level and by the policy level for maximum impact.

High quality of pre- and in-service education

To prepare teachers in the best way possible for their teaching, quality assurance is pivotal.

→ In the ICSE Academy we initiated job-shadowing across countries for peer-learning of course leaders. This job-shadowing across countries proved to be of enormous value in terms of getting new input on professional development provision and reflecting on one's own way of running courses.

→ Most teacher educators are researchers with a limited education in running courses. On the policy level, a new value system of engaging teacher educators at university, also taking into account their capability of teaching, would be helpful.

→ To avoid too many early-drop outs of the teaching career, mentorship programms for early-career educators are needed.

Incentivizing interdisciplinary STEM education at schools

For a high quality interdisciplinary STEM education an interdisciplinary subject «STEM» should be established in curricula. To further incentivise STEM education, schools need to be equiped with STEM laboratories at the newest level allowing students to do up-to-date research and experiments.

Integration of Technology

The integration of technology into STEM education is pivotal for enhancing learning experiences. Embracing cutting-edge technologies allows teachers to create dynamic and engaging lessons that resonate with students. Artificial Intelligence (AI) is recognized as a powerful tool in education, offering personalized learning experiences, facilitating real-time feedback, and enabling advanced data analysis to inform instructional decisions.

→ Given the huge impact AI is going to have, workshops on AI raise teachers interest. Courses offered within the ICSE Academy and within the ICSE series 1h4 teachers showed a high interest of teachers in these courses. The same holds e.g. for courses on 3D-printing or molecular cuisine, thus cutting-edge topics.

→ Educational policy can support the integration of technology in STEM education by providing the needed tools at school.

National-Level Training

Addressing STEM education at the national level within the EU reveals varying levels of implementation and prioritization across

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member countries. There is a clear need for more targeted national-level training initiatives aimed at equipping teachers with the necessary skills and knowledge to effectively deliver STEM education.

However, it is also highly important to foster environments (projects, working groups on EU level) where best practices and policies can be exchanged among EU countries so as to enhance educational outcomes.

Development of an up-to-date STEM curriculum

Given the development of society in relation to technology and information provision, the performance of students and their interest in science and science careers, as well as the limited time on task in STEM teaching, the STEM curricula need to be updated urgently. They need to be purified in terms of simply practicing skills that computers can take over and instead incorporate aspects that are necessary for living in our society as responsible citizens.

Assessment Practices

Effective assessment practices are critical in STEM education for fostering student learning and growth. Utilizing constructive, interactive, and formative assessment methods helps educators gauge students' understanding and progress in real-time. These practices not only provide valuable feedback to students but also inform instructional decisions, allowing teachers to adapt their teaching strategies to meet individual learning needs effectively.

→ To prepare teacher for these assessment practices, AI is a valuable tool. Therefore courses on how to use AI for assessment are important.

→ Formal assessment strategies also need to be changed. High stake examinations lead to teaching to the tests and prevent teachers from providing up-to-date STEM education. Alternative forms of tests like providing solutions to real life problems and questions (

in open schooling), developing products answering to real needs, project presentations and portfolios should be established in schools and reduce the number of high stake assessments.

Appreciating the performance of teachers in school

Whilst in some countries the profession of teachers is well appreciated, in other countries teachers are e. g. considered to be overpaid and only working half day. Such pictures are fostered both by parts of society and policy makers.

→ To ensure a high-performing workforce at schools, it is essential to appreciate the exhausting job teachers fullfil and to support them in very possible manner.

→ Adequate salaries, an adequate number of lessons to teach (to have time to prepare them throroughly) and smaller classes as well as interesting career options could raise the attractiveness of the job.

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