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SCIENCE,

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ENGINEERING AND

MATHEMATICS

Education Policies in Europe

SCIENTIX OBSERVATORY REPORT - OCTOBER 2018

European Schoolnet

Texas Instruments

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PUBLISHER: European Schoolnet (EUN Partnership AIBSL), Rue de Trèves, 61, 1040 Brussels, Belgium

PLEASE CITE THIS PUBLICATION AS: European Schoolnet (2018). Science, Technology, Engineering and Mathematics Education Policies in Europe. Scientix Observatory report. October 2018, European Schoolnet, Brussels.

KEYWORDS: Science, Technology, Engineering and Mathematics (STEM); European initiatives; Teacher training; Professional development; STEM reforms; Teacher recruitment; STEM resources; Curriculum integration

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PRINT RUN: 500 copies

ISBN: 9789492913500

PICTURE CREDIT: vasabii, Monkik, Becris, alice-photo, fotohunter, science photo, Marish Oksana Kuzmina, Sensay, AVAVA, Undrey, Wayne0216, goir, Triff/ Shutterstock.com

Published in October 2018. The views expressed in this publication are those of the author and not necessarily those of EUN Partnership AISBL or the European Commission.

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Executive summary

Studies funded by the European Commission or conducted by Science, Technology, Engineering and Mathematics (STEM) communities such as the STEM Alliance have highlighted major issues regarding the situation of STEM in European education systems: the low attractiveness of STEM studies and careers, or the unmet labour-market needs in STEM-related sectors that are expected to grow in the future.

To address these problems, many initiatives and programmes have been pursued, such as "The New Skills Agenda" initiative from the European Commission to focus on improving the quality and relevance of STEM skills development, to promote STEM studies and careers and to support teachers' professional development. They are supplemented in some countries by national approaches to deal with STEM issues.

In this context, Texas Instruments and European Schoolnet, with the support of Scientix, joined forces to conduct a study on STEM education policies and STEM teachers' practices, with a focus on 14 European countries[1]. The study aims to nourish the European public debate on STEM education by providing information on STEM policies and STEM teachers' practices. The first part of the study, which consists of this report, highlights the main trends of public education policies carried out in Europe in favour of STEM and proposes general observations and synthetic recommendations. Industry and university stakeholders took part in the study by providing their insights. STEM representatives from 14 European Ministries of Education answered a comprehensive survey documenting their actions and ambitions for developing STEM education.

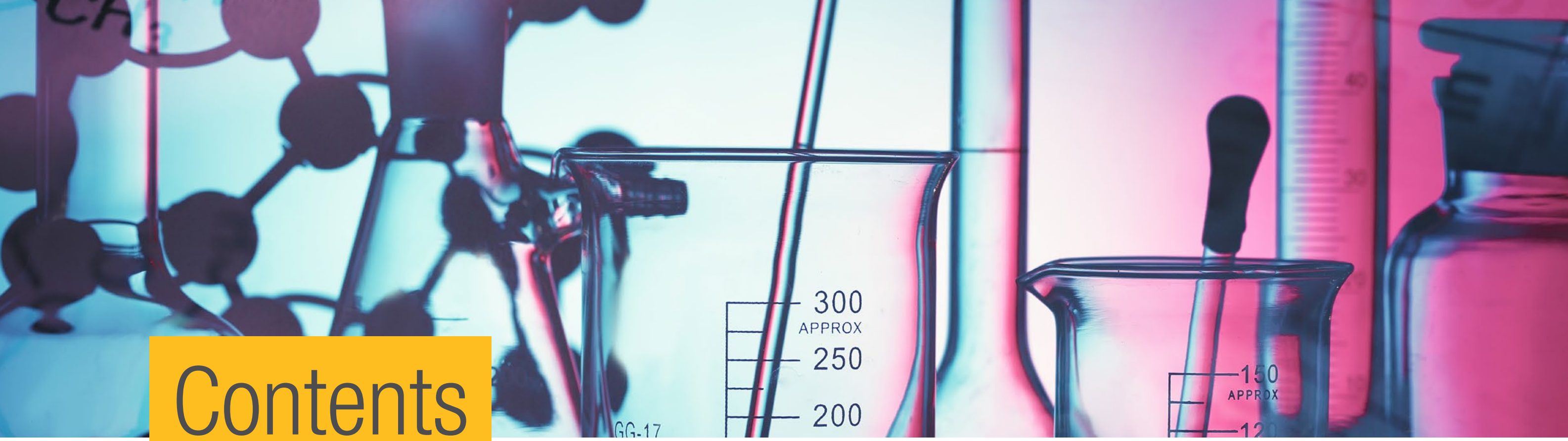
Through this study, the actors consulted for this work outlined potential solutions to STEM challenges:

1. Attracting more students and teachers to STEM education through a global approach from primary to adult education that will better anticipate the skills needed for the society of the future;
2. Breaking down the barriers between subjects with pragmatic initiatives (teacher training sessions, publishing contents, sharing best practices, etc.) to improve the quality of STEM education by building on each country's strengths;
3. Evaluating and integrating curriculum and pedagogical innovations: all energies must be oriented in the right direction with value added purpose-built technologies and services that need to be provided; positive experimentations need to be rolled out across the entire education system and disseminated among European countries (sharing of best practices, ideally in line with a common European framework);
4. Developing a common European framework of reference for STEM education and coordinating national STEM initiatives related to publishing pedagogical content to ensure teachers' needs are being met;
5. Fostering deeper collaboration with universities and industry to develop STEM teachers' skills.

These five points reveal a major strategic issue. While European countries participating in the study described their ambitions and actions regarding STEM education, it is difficult to observe at present the implementation of an integrated strategy involving all the domains and actors concerned on a national or European scale.

To cope with the fast pace of technological innovation, European education systems need a better vertical integration of their STEM policies with better relations between schools, universities and companies in STEM fields. They need a better horizontal integration too for developing a balanced approach between the different parts of the STEM block of subjects.

1 Austria, Belgium (Flanders), Denmark, France, Greece, Hungary, Italy, Lithuania, Malta, Portugal, Romania, Slovakia, Spain and Turkey.



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Introduction

Studies funded by the European Commission or conducted by Science, Technology, Engineering and Mathematics (STEM) communities such as the STEM Alliance have highlighted major issues regarding the situation of STEM in European education systems: the low attractiveness of STEM studies and careers, or the unmet labour-market needs in STEM-related sectors that are expected to grow in the future.[2] These issues echo the results of international benchmarks like The OECD Programme for International Student Assessment (PISA) or IEA's Trends in International Mathematics and Science Study (TIMMS). European countries are lagging behind in mathematics and science and, despite efforts since 2012, little progress appears to have been made.[3]

To address these problems, many initiatives and programmes have been pursued. The European Commission has launched "The New Skills Agenda"[4] initiative to focus on improving the quality and relevance of STEM skills development, to promote STEM studies and careers and to support teachers' professional development. It is supplemented in some countries by a global approach to deal with STEM issues at the national level.

In this context, Texas Instruments and European Schoolnet, with the support of Scientix, the community of science education in Europe, joined forces to conduct a study on STEM education policies and STEM teachers' practices, with a focus on 14 European countries. The study aims to nourish the European public debate on STEM education by providing information on STEM policies and STEM teachers' practices. The first part of the study, which consists of this report, highlights the main trends of public education policies carried out in Europe in favour of STEM and proposes general observations and synthetic recommendations. The second part of the study focuses on teachers' practices (secondary schools, pupils aged 10 to over 19).

This report is based on data gathered from sector experts. A survey was sent to STEM representatives from 14 European countries with questions on the place of STEM in the education system, the reform projects linked to STEM education, the situation regarding the professional capacity-building of STEM teachers and the development of specific pedagogical and learning resources. The structure of the report reflects that of the survey. The data collected was enriched with interviews with industry and university representatives to obtain feedback and points of view from the field.

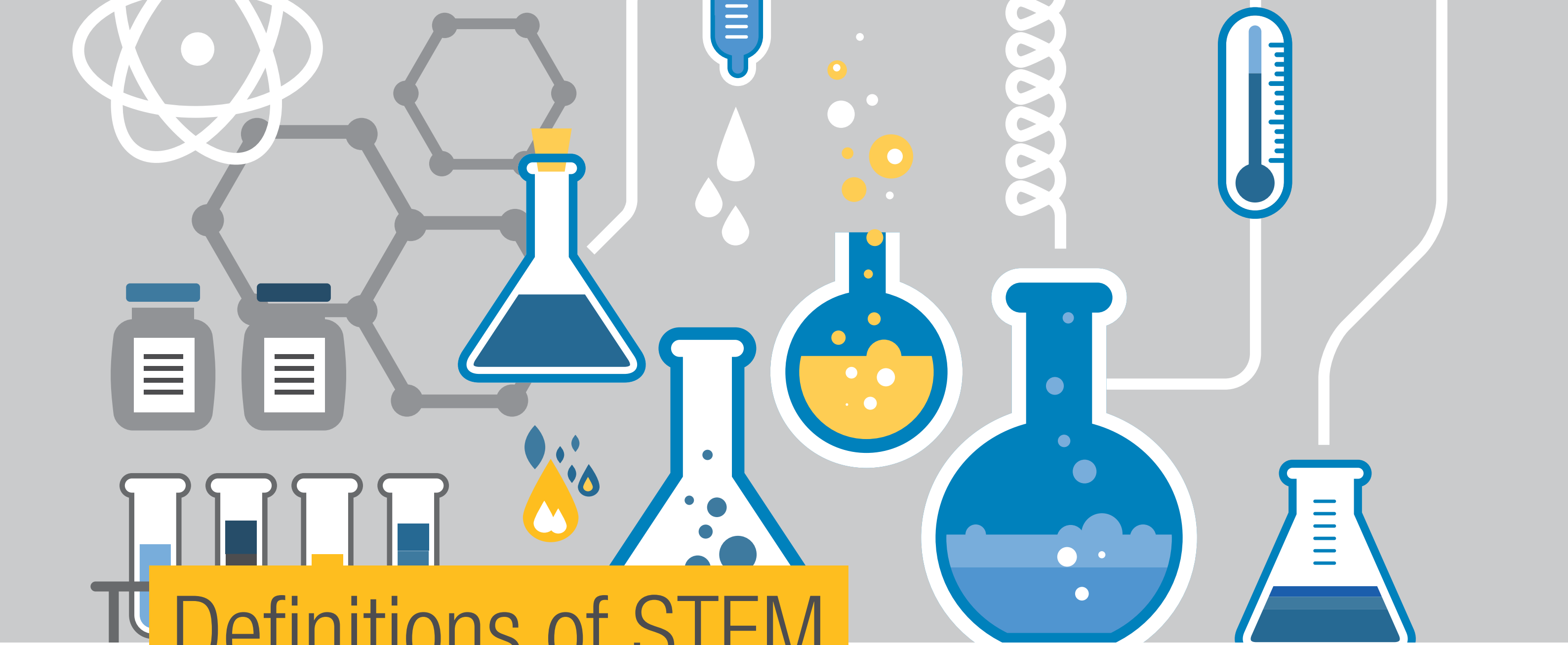
2 The Danish Technological Institute proposes a larger list of issues:

- STEM skills are associated with advanced technical skills, which are seen as strong drivers for technology and knowledge-driven growth and productivity gains in high-tech sectors, including ICT services.
- Due to demographic developments, there will be a strong replacement demand for high-skilled professionals working in STEM-related occupations in the coming years. This has led to concerns that Europe could lack an adequate supply of STEM skills to enable its future economic development (European Parliament - Committee on Employment and Social Affairs, 2013).
- Europe has a comparatively poor record of attracting top-level STEM professionals from abroad. Whereas, in the USA, 16 % of scientists come from outside the USA, only 3% of scientists in the EU come from non-EU countries (The Observatory on Borderless Higher Education, 2013).
- Concerns about the quantity and also at times the quality of STEM graduates.
- In spite of a series of measures, female participation in STEM studies, in particular in engineering, remains low in most EU Member States.

Danish Technological Institute, "Does the EU need more STEM graduates?" (2015). https://publications.europa.eu/en/publication-detail/-/publication/60500ed6-cbd5-11e5-a4b5-01aa75ed71a1/language-en [Accessed: July 2018].

3 For information on the PISA, TIMMS, ET2020 benchmarks regarding European countries performances, refer to European Schoolnet. "STEM Alliance, STEM education Factsheet" (2017) http://www.stemalliance.eu/documents/99712/104016/STEM-Alliance-Fact-Sheet/4ae068f4-ca07-459a-92c9-17ff305341b1 [Accessed: July 2018].

4 For information on the "New Skills Agenda", refer to European Commission. "New Skills Agenda for Europe". http://ec.europa.eu/social/main.jsp?catId=1223 [Accessed: August 2018].



Definitions of STEM

Coined by the US National Science Foundation in the 1990s, the STEM acronym, standing for "science, technology, engineering and mathematics" continues to be a source of ambiguity among practitioners, particularly in the area of education.[5] Definitions of STEM range from simple referencing of the four discrete fields indicated in the acronym, to educational approaches at the intersections of any number of the four disciplines, to a fully integrated view of STEM education.[6]

When STEM education is placed at the "intersection" of science, technology, engineering and mathematics, its meaning is usually expanded to refer to a rupture with "traditional" teaching. An integrative STEM education usually implies multidisciplinary teaching and is directed at developing students' problem-framing and problem-solving skills, as well as their ability to contextualise scientific concepts to real-life situations. In this understanding, STEM education is not defined in terms of a break with traditional subjects, but rather with a break from traditional instruction, in which lessons are strictly focused on the delivery of subject-specific content by the teacher and the acquisition of content knowledge by the students.

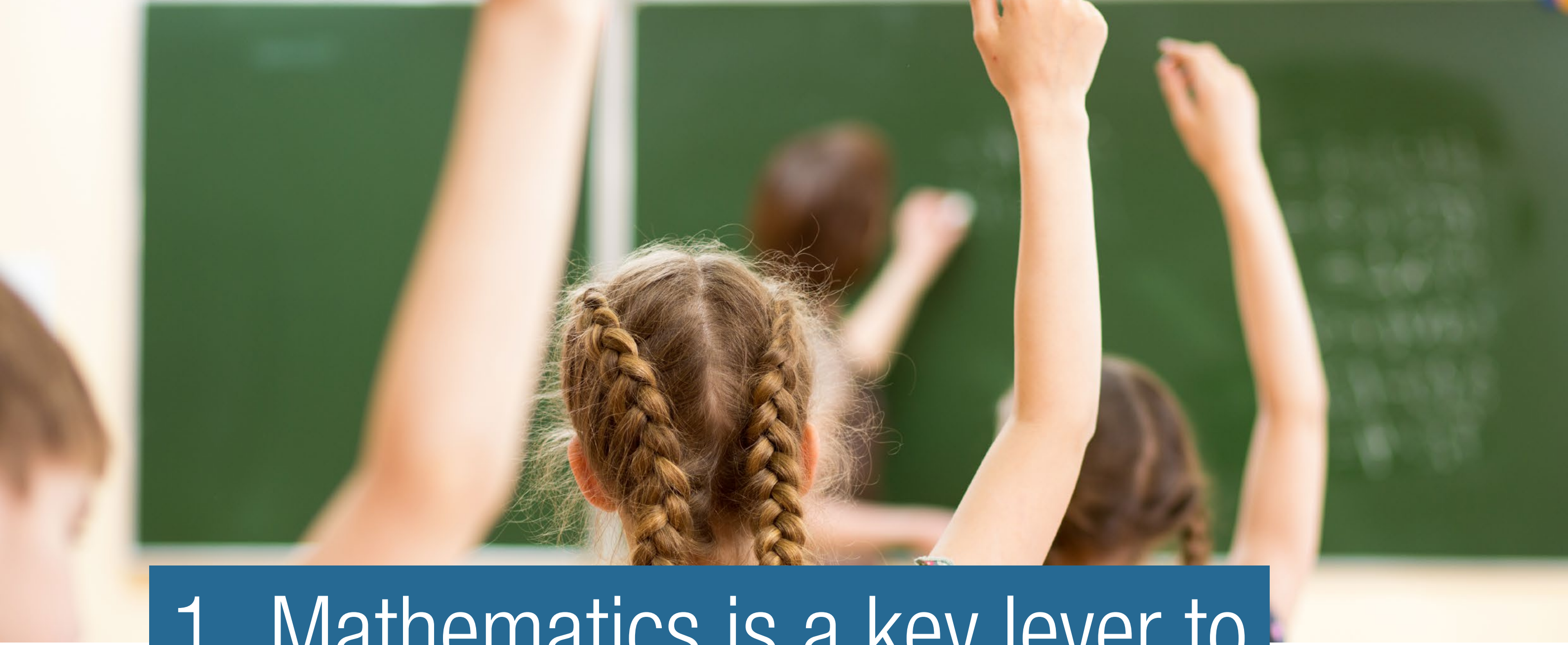
At the level of European countries, however, there is no common understanding of what STEM refers to. In most national and international reports, STEM teaching is usually interchangeable with "science teaching", a term used to refer to "*all of physical sciences, life sciences, computer science and technology, and [...] includes mathematics – subjects that are commonly taught at primary and secondary schools in most European countries*"[7] – in other words, to the various domains of knowledge covered by the acronym.

To avoid confusion between the various definitions of STEM and the various educational approaches that can be implicit in the acronym, for the purpose of this report, STEM was used to refer to all subjects which are included under the four domains of Science, Technology, Engineering and Mathematics, regardless of how they are approached in the classroom. The upcoming report of the series, focusing on STEM Education *Practices*, will shed a new light on the way STEM is approached in practice in classrooms throughout Europe.

5 Sanders, Mark E. "Stem, stem education, stemmania." (2008). https://vtechworks.lib.vt.edu/bitstream/handle/10919/51616/STEMmania.pdf?sequence=1&isAllowed=y [Accessed: September 2018].

6 See, for example: Rosicka, Christine. "Translating STEM education research into practice." (2016). https://research.acer.edu.au/cgi/viewcontent.cgi?article=1010&context=professional_dev [Accessed: September 2018], or DeCoito, Isha. "Focusing on science, technology, engineering, and mathematics (STEM) in the 21st century." *Ontario Professional Surveyor 57,* no. 1 (2014): 34-36. https://www.krcmar.ca/resource-articles/2014_Winter_Focusing%20on%20STEM_0.pdf [Accessed: September 2018].

7 European Commission. High Level Group on Science Education, European Commission. Science, Economy, and Society. *Science education now: A renewed pedagogy for the future of Europe.* Vol. 22845. Office for Official Publications of the European Communities, 2007. https://www.eesc.europa.eu/sites/default/files/resources/docs/rapportrocardfinal.pdf [Accessed: September 2018].



1. Mathematics is a key lever to transform STEM teaching and learning

1.1. MATHEMATICS IS A MAJOR SUBJECT IN STEM EDUCATION

1.1.1. The prominent place of mathematics

In most European countries mathematics is taught as a mandatory and major subject during the first years of school.[8] During primary and lower secondary education, it is the principal subject taught among STEM subjects (59% of STEM hours in DK,[9] 50 to 70% in FR depending on the level, around 66% in IT, 38 to 69% in LT, 42 to 80% in MT, 33 to 70% in PT, 33 to 80% in RO).

In upper secondary education, STEM subjects (e.g. Physics, Biology and Technology) are taught more broadly. As more STEM subjects enter the timetable, the proportion of mathematics decreases among STEM teaching. However, mathematics remains a major subject (30 to 40% in FR for general track and around 25% in engineering/science tracks, around 33% in GR for science studies, 40 to 50% in HU, 45% in general track in IT and 35% in engineering/science tracks, 25% in LT).

For most of the European countries surveyed, mathematics is part of the final examination to enter university or at the end of high school (e.g. AT, DK, FR, HG, IT, MT, PT, RO, SK). In LT, mathematics is not mandatory for the final examination. However, students must choose elective examinations and mathematics is among the most popular ones. In TK, mathematics is mandatory during the first year of high school (around 50% of the STEM courses taught) and is sometimes included in elective courses later on. However, it is part of the final examinations (22% of the questions for high school entrance exam and 33% of the questions for the basic proficiency test section of the university entrance exam).

1.1.2. If you want to transform STEM education, you must consider mathematics

Mathematics is a preponderant subject in education and applied mathematics are also important in other STEM subjects (e.g. in Biology, Physics, Chemistry, etc.): this domination of mathematics does not seem to have diminished. In FR for example, in a letter to the president of the organisation in charge of national curriculum design, the Minister of Education wrote that he would like to "make sciences more mathematical".

8 For information on European education systems school levels, refer to European Commission/EACEA/Eurydice. "The Structure of the European Education Systems 2016/17: Schematic Diagrams. Eurydice Facts and Figures". Publications Office of the European Union. https://publications.europa.eu/en/publication-detail/-/publication/becafa9c-9a85-11e6-9bca-01aa75ed71a1/language-en [Accessed: July 2018].

9 Countries are abbreviated using country codes available on page 26 of this report.

Some countries are already beginning to introduce a new set of methodologies in teaching mathematics. In RO, the latest curriculum reform for primary and lower secondary education promotes project-based learning, collaborative learning, inquiry-based learning, personalised and differentiated learning. In DK, in both primary and secondary schools, mathematics education is embedded with the use of ICT tools and delivered through project-based learning. In FR, in lower secondary education, the latest curriculum reform in 2015 embedded coding in mathematics. In upper secondary Education, since September 2018, teaching coding in mathematics using programming language such as Python is mandatory for more than 500,000 grade 10 students entering Senior High School.

Improving STEM teaching requires a deep consideration of mathematics. Success in mathematics is key for STEM students: maths teachers could benefit from specific training on new methodologies and more experimentations on how maths is taught could be conducted to diminish the failure rate of students in maths that affects their STEM academic careers. Maths teachers could turn to the other STEM subjects to integrate project-based, inquiry-based and research-based approaches already in use there. Often, there are few relations between mathematics as a subject and other science subjects at secondary level; these silos are also a strong reality in higher education.

UNIVERSITY VOICE

The STEM block does not exist in higher education either: there is a traditional and strong frontier between science faculties (including Mathematics, Physics, etc.) and engineering faculties. Silos are dominant in universities, except for ICT and coding courses, which are more transversal.

1.2. INNOVATIVE PEDAGOGICAL APPROACHES ARE FOUND IN OTHER STEM SUBJECTS

1.2.1. General track: research-based methodologies on the rise

The other STEM subjects are taught with different formats and methodologies. In GR, many STEM and experimental activities take place in the science laboratory available in all high schools and teachers implement activities during the school year. The Greek curriculum includes inquiry-based classes for every student. In LT, education can take place outside school (for practical and theoretical courses), e.g. in museums, parks, etc., by adjusting the educational process (active education of pupils, personalised learning, managing groups of various sizes depending on activities, etc.).

We begin to see new methodologies arising in the teaching of many STEM subjects. In RO, the methodological part of the STEM curriculum (the guidelines for teachers) states the importance of formative assessments and the use of specific software (e.g. Kahoot, GeoGebra, etc.). In Physics, Inquiry-Based Science Education (IBSE) is promoted. In DK, school students are learning the basic tools and techniques for design, wood and metalwork through practical work so as to be able later to choose autonomously the appropriate working method, tool, technique and machine for a specific task when they are involved in pedagogical projects. In SK, most schools and teachers have changed their methods of education to support student learning through cooperation, with emphasis on discovering existing knowledge not only through digital technologies, but also through observation of nature and natural phenomena. In an increasing number of classes, teachers use active experiments made by students to discover, measure, analyse, evaluate and interpret various natural and technical phenomena.

This trend is not new, but inquiry-based activities and research-based education are mentioned by most of the European countries participating in the study. These methodologies seem

increasingly to challenge the traditional dyad of "frontal theoretical courses" and "applied exercises".

University and private company stakeholders point to the mismatch between students' skills and what they are expected to do in higher education or as engineers. Promoting a project-based and problem-based approach is important to secure students' motivation but they need to be able to apply demanding R&D approaches soon, meaning that they need to drop the "how to" state of mind – applying "recipes" to already known problems – to adopt a "why?" state of mind, inquiring about problems that are not yet documented.

UNIVERSITY VOICE

Pedagogical approaches are divided into frontal/fundamental courses and project-based/technically advanced courses: technically advanced courses are more suitable for innovative pedagogical practice such as flipped classrooms; some lecturers are providing 100% project-based courses with exams also based on projects (assessing students through collaborative teamwork).

UNIVERSITY VOICE

Universities and engineering schools are adapting to the enlargement of student cohorts, in competition with other programmes for excellent students: fundamental skills in sciences are weaker and students are more motivated by process and project-based pedagogical approaches ("how to") than by research and inquiry-based pedagogical approaches ("why?"); there is a lack of PhD candidates in technical fields (embedded system design, controller design, etc.)

INDUSTRY VOICE

Shadowing practices are no longer sufficient, in-house training, on-the-job training and mentorship are needed to deal with candidates who are not really skilled in technical domains: this onboarding period is being continuously extended and made more complex (different kinds of training) to deal with under-skilled candidates, heterogeneous candidates or candidates who don't really know what they want to do and ask for a "tour" or "samples" before choosing an activity (some programmes allow new students to discover a range of diverse activities for several months with mobility available for them if they change their minds); candidates are interested in their next move and need information on short-term career progression (3 to 5 years).

1.2.2. Specialisation tracks: a major source of elective STEM courses

In some countries, an emphasis on STEM is also made through specialised tracks: when students reach their final years of secondary education they can choose to add more STEM to their academic paths. In FR, in high schools, students can choose between the general track (with an emphasis on either Mathematics, Physics/Chemistry or Earth & Life Sciences in their last year) and the Engineering Sciences track (adding 8 hours per week of Technology education). During Junior High School, they learn how to code before moving to Senior High School where, since last September 2018, it is mandatory for all grade 10 students (0.5 million) to learn algorithms and how to code them using Python as the programming language. Moving forward, a major new reform for upper education will be implemented in 2019; the reform is expected to end existing specialisations (such as the scientific stream), but STEM education will be part of general education for every pupil. A new "Scientific education" subject will be introduced, offering a transdisciplinary approach to STEM. Pupils interested in sciences will be able to choose three (at the "première" level - the penultimate year of upper secondary school) or two (in "terminale" - the last year of upper secondary school), STEM specialisations in either of the following subjects: Maths, Physics-Chemistry, Earth and life, Engineering sciences, Numeric and computer sciences. In AT, students are involved in Mathematics, Natural Sciences and Technology depending on the educational path chosen (academic school or VET). In HU, it is possible for students to specialise in Physics, Chemistry, Biology, Mathematics. They can also go to vocational secondary schools where these subjects are replaced by basic vocational subjects and engineering. In LT, pupils can choose subject modules, including STEM modules, according to their interests and abilities. In MT, students must choose two other subjects (apart from Mathematics and usually Physics) for specialisation from a list of around 24 subjects: STEM is represented by Chemistry, Biology, Computing and some vocational education and training subjects (Health & Social Care, Engineering, Agribusiness). In PT, students have to choose between scientific-humanities courses and vocational courses at the end of lower secondary school. Within scientific and humanities courses, students choose the more specific course they wish to take between Sciences and Technologies, Visual Arts, Socioeconomic Sciences, Languages and Human Sciences. In RO, students can choose a specialisation from the ninth grade in Mathematics-ICT (~18%), Natural Sciences (~14%), Technological Studies (~36%), Social Sciences and Philology (~30%) and Vocational Studies (~2%).

STEM education stakeholders need to be conscious that they are onboarding students for their STEM academic journey primarily through mathematics. To open the door of mathematics to students is to open the doors of STEM: maths should not only be a way to guide the best students towards excellent higher education programmes, but its prevalence should also be leveraged to open the horizon of all students towards STEM. Maths could be used as a gate to promote STEM disciplines: but to do this effectively, it seems necessary to strengthen the links between maths teachers and other STEM teachers, to promote integration between the different subjects of the STEM block and to adopt attractive (project-based and personalised) pedagogical approaches for students

However, making mathematics accessible for the majority of students is not the only challenge to focus on. Increasingly, students are composing their academic path on their own: if they are not motivated by STEM subjects, they will not choose STEM subjects in high school. If STEM is a real national priority, governments should consider implementing a serious integrated marketing approach to promote STEM.

UNIVERSITY VOICE

In recent years (compared with five to ten years ago), students have appeared less autonomous, demanding more feedback and adapted/personalised activities, especially project-based courses. They are more comfortable with practical activities.

UNIVERSITY VOICE

A few institutions have developed a "marketing approach" to promote technical engineering programmes. But lecturers are mainly promoting their Bachelors' or Masters' courses on their own: they communicate on the employability of their students in trendy industrial fields such as IoT [Internet of Things], autonomous driving, robotics, etc.

Lecturers are convinced that the promotion of their technical engineer training programmes must be developed through collaboration between the public sector (secondary education especially), companies and universities: students do not have accurate information about the opportunities, salaries and career developments provided by their programmes.

1.3. MANY PERIPHERAL INITIATIVES MORE OR LESS CONNECTED TO CURRICULUM

1.3.1. Ecosystems approaches

In addition to these general and specialised STEM courses, there is a pool of initiatives conducted by non-profit organisations, companies, teachers' professional organisations, etc., to promote interest in STEM. In GR, the following competitions are offered:

- the national competition of open robotics and physical computing (GFOSS and Hellenic Universities),
- the national educational robotics competition (WRO Hellas),
- the national coding competition (Greek Computer Society),
- STEM competitions (space, racing, etc.) (Hellenic Universities),
- EUSO (European Union Science Olympiad) competition (Union of Science Teachers),
- the national Scratch games competition (school advisers and the University of Crete) https://robotics-edu.gr/.

In PT, the Ministry of Education and IBM Portugal support the "Teachers Try Science Project". This project includes the use of digital technologies and the relationships between different schools, ages and disciplines. In ES, the Xplore Health project[10] coordinated by the Spanish IrsiCaixa and "la Caixa" Foundation develops participative multimedia and hands-on resources with the aim of decreasing the gap between health research and education. It promotes IBSE and the interaction of students with different social actors with the aim of preparing them to become active citizens in the knowledge society. In BE (Flanders), cooperation at school level with third parties, e.g. STEM businesses and sectors, is becoming increasingly mainstream. The Dual Learning model employed in the Flemish VET system which has been set up over the past few years is gaining ground at a swift pace. The model combines student placement in industry with part-time education fostering sustainable school-industry partnerships. In FR, the public educational publishing house CANOPé has launched a resource platform developed with industrial partners. Although the project depends on partnership opportunities, while its adoption is still confidential, high quality pedagogical content is being published regularly.[11]

At European level, the STEM Labs initiative from T³ Europe[12] is an example of cooperation between educators and industry. Over 30 schools with a very high STEM profile from across Europe and the Middle East exchange classroom experiences within the network. They disseminate best practice examples in various formats of professional development and educational content. The STEM Lab concept has been initiated by the T³ Europe educator network, the participating schools are further developing it, and the industry partner Texas Instruments supports it with financial resources and administration support.

At the international level, the International Centre for STEM Education (ICSE)[13] is an open consortium of universities across Europe which aims to raise students' interest in STEM, their achievement levels and process-oriented competences. ICSE focusses on practice-relevant research and its transfer into practice by establishing sustainable links between stakeholders from research, practice, policy and industry. MaSDiV,[14] IncluSME[15] and STEM PD Net[16] are current projects of ICSE.

Whether through partnerships or internal programmes, there are many very varied initiatives of this type. They do not appear systemically connected to the curriculum and they are far from being adopted by most schools and teachers on a national scale. The public sector seem to be looking for opportunities without privileging a truly coordinated national approach. The advantage is

10 Cf. http://www.xplorehealth.eu/en [Accessed: August 2018].
11 Cf. http://eni.crdp-paris.fr/ [Accessed: August 2018].
12 Cf. http://www.t3europe.eu [Accessed: August 2018].
13 Cf. https://icse.eu/ [Accessed: August 2018].
14 Cf. https://masdiv-project.eu/ [Accessed: August 2018].
15 Cf. https://inclusme-project.eu/ [Accessed: August 2018].
16 Cf. http://stem-pd-net.eu/en/ [Accessed: August 2018].

that creativity and innovation are in the spotlight. The disadvantage is that it is difficult to measure the impact of these programmes and therefore their overall efficiency. If measured, the positive outcomes of these experimental or innovative programmes could be integrated in a structured national programme more connected to STEM curricula.

UNIVERSITY VOICE

Various programmes are developed by universities and schools to attract students but the impact is not really measured in terms of recruitment or reputation and the lecturers involved in this kind of programmes have a hard time valorising this engagement for their career:

- Short internships in university science labs (1 to 5 days),
- Mentoring projects in high schools,
- Science events (hackathons, makers' fairs),
- Seminars or lectures by university staff in high schools.

INDUSTRY VOICE

Programmes are developed with universities to offer internships, apprenticeships and research projects. Some managers are developing personal relations with academics. Communicating on up-to-date R&D projects helps to get students' interest (IoT, embedded systems in the automotive industry, etc.). Cooperation programmes with universities are implemented to communicate activities and technical engineers take on the role of informing students about their future careers.

1.3.2. Internal innovative projects

There are also innovative projects that do not include partnerships. In GR, at all levels of education, there are hours in the curriculum dedicated to implementing STEM activities. For all STEM subjects there are guidelines from the Ministry of Education and the Institute of Educational Policy, for the implementation of STEM activities. In DK, Technological Literacy is an elective subject and compulsory as an element of various subjects. It aims to give students a background of technological competencies required for the labour market.

In MT, many STEM-related initiatives are organised during the school year to promote further uptake of STEM subjects by students for them to pursue science-related careers. These initiatives include the Science Safari, Teen Science Café, X'hemM?, D&T Expo and Maths Venture. Other events, such as Malta Junior Science Olympiad, Maths Olympiad, Malta Robotics Olympiad, High 5 and Go4Research, target gifted and talented students. In LT, several events are organised to support and promote interest in STEM studies or careers, such as the yearly "Spaceship – Earth"[17] science festival, the Researchers' Night event, as well as yearly Olympiads of various STEM disciplines[18] and other national mathematical and natural science literacy contests.[19] In RO, there are yearly Olympiads in different STEM subjects (Mathematics, ICT and Coding, Biology from age 11, Physics from age 12, Chemistry from age 13). There are also integrated STEM Olympiads: Earth Sciences, the Science Olympiad for Juniors, Astronomy & Astrophysics, etc.

These kinds of initiatives enable students to participate and practise STEM together with educators, academics, the research community, parents, professionals, etc. They change teachers' practices by familiarising them with modern training methods and learner-centric approaches. However, these guidelines and programmes do not involve the whole of the student population and depend on the investment of local educational communities.

17 Cf. https://www.mokslofestivalis.eu/ [Accessed: August 2018].
18 Cf. http://www.lmnsc.lt/lt/olimpiados_struc_0141 (in Lithuanian only) [Accessed: August 2018].
19 Cf. http://www.egzaminai.lt/561/ (in Lithuanian only) [Accessed: August 2018].

2. Main motivations regarding STEM reforms[20]

Analysis of the answers of STEM representatives from 14 European countries reveals the emergence of two main motivators for changing the way of teaching and learning STEM.

2.1. FIRST MOTIVATION: DIGITAL CULTURE FOR THE CITIZENS OF THE FUTURE[21]

The rise of the digital economy has made knowledge related to ICT, coding, robotics, etc. necessary for current citizens but even more so for future citizens. To face this challenge, European countries are reforming their STEM curricula to introduce courses to encourage digital skills. In BE (Flanders), from 2019 onwards, every two years, new attainment goals will be introduced which will span the whole Flemish compulsory curriculum, from primary education to the higher grades of secondary schooling. The public debate which was held (2015) to inform these new developments expressed a clear public interest in integrating STEM. A first set of specific STEM attainment goals have been developed with the aim of being brought before the Flemish Parliament in autumn 2018. STEM is one of the 16 Key Competences which form the base of the new Flemish Curriculum. Key to these developments were the impact of “technological, scientific and ICT developments” in society, as well as the need to link education with the labour market among the primary motives behind the Government’s STEM reform, as mentioned in the STEM Framework for Flemish Schools.[22]

In RO, the new reform has introduced ICT and informatics from middle school. In ES, working groups are debating the inclusion of these topics in the curriculum and some of the autonomous regions have already included coding in their curriculum. In AT, the “Schule 4.0” initiative aims to implement coding for all students in the educational system. In GR, since 2010, ICT has been included as a subject in 1200 pilot primary schools and since 2016 in all primary schools of the country. Coding and robotics are taught in middle schools. In IT, there are recommendations regarding the relevance of computational thinking and its connection with robotics and coding, to promote pupils’ analytical skills. In LT, since 2017 there has been a pilot of ten primary schools for developing teaching/learning

20 For a detailed panorama of STEM policies initiatives in Europe, see Kearney, Caroline, “Efforts to Increase Students’ Interest in Pursuing Mathematics, Science and Technology Studies and Careers. National Measures taken by 30 Countries – 2015 Report.” (2016). http://www.scientix.eu/observatory/comparative-analysis-2015 [Accessed: July 2018].

21 “Fully [participating] in the digital world” is also mentioned as the first motivation of European countries interested in introducing computational thinking in their STEM curricula in Bocconi, Stefania, Augusto Chioccariello, Giuliana Dettori, Anusca Ferrari, Katja Engelhardt, P. Kampylis, and Y. Punie. “Developing computational thinking in compulsory education.” European Commission, JRC Science for Policy Report (2016). http://publications.jrc.ec.europa.eu/repository/bitstream/JRC104188/jrc104188_computhinkreport.pdf [Accessed: July 2018].

22 Department of Education and Training (Belgium - Flanders). “STEM Framework for Flemish Schools. Principles and objectives. Flanders state of the art”. (2016) https://onderwijs.vlaanderen.be/sites/default/files/atoms/files/STEM-kader%20%28Engels%29.pdf [Accessed: September 2018]

material and preparing recommendations for the integration of informatics into the primary education curriculum.

In addition to these capabilities, governments tend to generalise a digital culture for all through national programmes focused on ICT. The trend is not new: for example, in FR, since 1979, every 5 to 7 years governments have launched a "digital plan for education". The main purpose noted is to help people to evolve in increasingly connected and digital societies. In IT, in 2015, the Italian Ministry of Education launched the *Piano Nazionale Scuola Digitale* (the National Plan for Digital School). This plan has several aims. The first is to provide schools with tools and conditions that allow full access to the information society. On the other hand, the plan aims to develop students' knowledge and skills in the digital field, in order to promote transversal competencies. One action is focused on supporting the development of computational thinking in primary schools; another aims to upgrade the technology curriculum in middle school. The plan also aims to promote digital competencies required for the job market. Moreover, the plan aims at filling the gender gap in careers that involve competencies in STEM areas.

The traditional mission of a national education system, "training future citizens and citizens for the future", is a challenge that is becoming increasingly complex. The pace of technological change is accelerating, controversies are multiplying (eugenics, privacy, nanomaterials, etc.) and teachers need to update their expertise more frequently. It is precisely this technological expertise that seems to be lacking within organisations, companies and education systems. If the national education system is not able to adapt to the pace, the whole country will lag behind.

UNIVERSITY VOICE

More and more devices with coding functions are being introduced into technical engineering training programmes: lecturers need to train themselves on these new types of devices and explore their pedagogical potential.

2.2. SECOND MOTIVATION: ATTRACTING STUDENTS TO STEM FOR THE JOB MARKET[23]

European states are implementing strategies and initiatives to increase the popularity of STEM studies and careers. In DK, the National Natural Science Strategy aims to contribute to increasing the number of young people who are interested in science in primary and lower secondary education and who choose natural sciences in high schools or in vocational STEM programmes. The second aim of this strategy is to increase the number of young people who are highly skilled in science subjects and vocational STEM programmes. In HU, the current reforms of the curriculum aim to have a pronounced effect on STEM subjects. The modernisation of the content and the new point of view may increase the popularity of STEM careers. In IT, the Italian Ministry of Education has promoted the Piano Lauree Scientifiche, a national plan that supports educational activities directed at encouraging careers in academic studies in the STEM areas. Universities are developing activities that directly involve high school students in laboratory practice. Another action of the plan aims to introduce innovative approaches for younger students in order to reduce school dropout. In MT, the DLAP (Directorate for Learning and Assessment Programme) is currently embarking on a number of STEM initiatives to:

- popularise sciences (increase STEM literacy),
- increase STEM uptake by promoting STEM careers,
- engage the gifted and talented with challenging STEM initiatives,
- reduce the gender gap in STEM.

23 "The need to develop new skills for the employment market" is also mentioned as the second motivation of European countries interested in introducing computational thinking in their STEM curricula in Bocconi, S., Chioccariello, A., Dettori, G., Ferrari, A., Engelhardt, K, "*Developing computational thinking in compulsory education – Implications for policy and practice*", 2016: http://publications.jrc.ec.europa.eu/repository/bitstream/JRC104188/jrc104188_computhinkreport.pdf [Accessed: July 2018].

In ES, autonomous regions, such as Galicia or Cataluña, have included detailed STEM education guidelines into their teacher training programmes, understanding that it is extremely important to have teachers with good skills in pedagogy applied to scientific fields to get high-performing students. The same applies to the Ministry of Education, Culture and Sport, where STEM education was included last year as a priority in the annual plan for teacher training.

Contrary to what was observed three years ago by researchers from the Scientix programme,[24] today, every country that participated in this study has education programmes for STEM. Governments are mostly responding to the European Commission and other public organisations who are publicising the huge number of ICT jobs vacancies. The forecasts range from 300,000 unfilled jobs in 2020 to 500,000 or even 900,000.[25] Indeed, shortages appear to be more pronounced for technological occupations (including ICT, but also engineering) and for professionals.[26] But the relation between ICT job vacancies and STEM education is not that simple. For example, according to a study by the Danish Technological Institute[27] shortages are not really related to a lack of volume of STEM students. Other factors explain this shortage:

- companies are not investing enough in continuous development to respond to the "baby boomers' retirement";
- companies want to hire senior profiles in emergent technological sectors;
- STEM students do not choose STEM careers systematically, and girls do not choose STEM even if they are succeeding in STEM education, at least as much as boys through primary and secondary education;
- European countries are less attractive than other countries for engineers;
- when European countries receive foreign students, they are doubtful about their competencies and they are unable to position them correctly in terms of skills;
- shortage is significant in specific European regions, among SMEs, and in specific technical fields but not all over Europe… highlighting issues related to the mobility of STEM graduates.

The problem is complex and needs an integrated and holistic approach: focusing on ICT engineers and overlooking analog design engineers, or reforming curricula without analysing student orientation patterns, are faults that governments with maturity on STEM reforms are trying to avoid.

INDUSTRY VOICE

The "baby boomers' retirement" is also a reality for technical engineering profiles. In the 1990s, the development of the software engineering sector attracted many profiles, and companies and universities/schools shifted their expression of needs and training capacities towards software engineering, so there is now an ageing population of technical engineers who were trained during the 1980s and who are retiring now or soon.

INDUSTRY VOICE

The competition for recruiting European engineers is difficult for companies that are not internationally or nationally renowned; in Germany, for example, GAFAM and big national firms (Bosch, Siemens, etc.) are attracting most engineers; American unicorn start-ups investing in continental Europe are also competitors (Tesla, Uber, etc.). Brand recognition is key to hiring excellent young engineers.

INDUSTRY VOICE

Nowadays when you want to attract engineering' profiles you need to raise salaries and accelerate careers. To sustain the weight of salaries you need more engineers to innovate and develop new products, and if you promise accelerated careers to engineers, it means that they spend fewer years on production activities to access management or business-oriented positions earlier.

24 Kearney, Caroline, "Efforts to Increase Students' Interest in Pursuing Mathematics, Science and Technology Studies and Careers. National Measures taken by 30 Countries – 2015 Report." (2016). http://www.scientix.eu/observatory/comparative-analysis-2015 [Accessed: July 2018].

25 Teffer, Peter. "EU overestimated ICT jobs gap". euobserver. 10 May 2017. https://euobserver.com/digital/137835 [Accessed: July 2018].

26 Caprile, M., R. Palmén, P. Sanz, and G. Dente. "Encouraging STEM studies for the labour market." Directorate General for Internal Policies, European Union (2015). http://www.europarl.europa.eu/RegData/etudes/STUD/2015/542199/IPOL_STU(2015)542199_EN.pdf [Accessed: September 2018].

27 Danish Technological Institute et al., "Does the EU need more STEM graduates?" (2015). https://publications.europa.eu/en/publication-detail/-/publication/60500ed6-cbd5-11e5-a4b5-01aa75ed71a1/language-en [Accessed: July 2018].

UNIVERSITY VOICE

Software engineering training programmes are influential in higher education. ICT courses and coding are introduced in most engineering degrees and often mandatory (replacing electricity- or electronics-related topics in high schools, preschools and at Bachelor's level). Programmes that are in between electronics and informatics are more popular than pure analog design / electro-technical programmes. With this evolution we are addressing the problem of lack of computer engineers. But we are leaving aside the lack of other specialties.

UNIVERSITY VOICE

Students are embracing diverse careers: consulting firms, investment banks, etc. are recruiting engineers from technical fields in competition with industrial companies. The regional economic ecosystem has a great influence on the orientation of engineering students (banks in Bristol/London, consulting firms in Milan, etc.): because of a poor industrial culture, students are targeting companies they discovered during their Bachelor's or Master's courses.

UNIVERSITY VOICE

The European and international mobility of students is a problem for lecturers more than an opportunity, especially at Master's level. Sourcing and recruiting good students requires time (interviews, assessments, etc.) and networks (agents, ambassadors, contact relationship management tools, etc.): standards or specific assessment are needed to assure that foreign students will succeed in an Italian, French, British or German Master's after a Bachelor's in their local universities.

3. How to support STEM teachers during their careers[28]

3.1. GOVERNMENT FOCUS ON IN-SERVICE TRAINING FOR TEACHERS

3.1.1. Partnership with industries or other organisations

Many European countries currently put emphasis on in-service training, creating partnerships with NGOs or industry. They have access to material support and external funding to develop teacher capabilities, STEM contents and innovative purpose-built technologies and methodologies.

In GR, Local Laboratories of Sciences (EKFE) and Local Centres for the Support of ICT (KEPLINET) regularly train science and ICT teachers in STEM activities, experimental activities related to their subjects and technically support the schools' computer laboratories. In FR, a special effort has been made for primary STEM teachers with the *La Main à la P*âte foundation to develop training sessions and resources to help teachers implement science education in their courses:[29] since 2012, the "houses for sciences" network has offered sessions in science teaching and partnership with universities. In IT, the M@t.abel action, organised with the Union of Italian Mathematicians and the Italian Society of Statistics, involves maths and sciences teachers in face-to-face activities, with the opportunity to create content on online platforms. Teachers can interact with colleagues and experienced tutors to analyse what happens in the classroom. In SK, there are many private educational companies and universities offering various STEM courses. Vocational schools are also developing their programmes with partners: they cooperate with companies to improve education, especially in engineering and technologically oriented subjects.

In Europe, T³ Europe is a network of STEM teachers that serves as an umbrella body for 12 country organisations to provide quality professional development, classroom-proven content and integrated state-of-the-art classroom pedagogy (www.t3europe.eu), supported by Texas Instruments.

The authorities are mobilising universities and collaborating with companies to develop the skills of STEM teachers. However, the commitment of universities or companies seems very uneven from one country to another. At European level, grants should be allocated for analysing the successful practices of the

28 For a detailed panorama of STEM teachers' skills development in Europe, refer to Kearney, Caroline, "Efforts to Increase Students' Interest in Pursuing Mathematics, Science and Technology Studies and Careers. National Measures taken by 30 Countries – 2015 Report." (2016). http://www.scientix.eu/observatory/comparative-analysis-2015 [Accessed: July 2018].

29 "*La Main à la Pâte*" develops several programmes in collaboration with the Ministry of Education such as "the houses of sciences", one of whose aims is to train teachers: http://www.maisons-pour-la-science.org/ [Accessed: July 2018].

most advanced countries and facilitating the dissemination of good practices internationally.

UNIVERSITY VOICE

Lecturers rely on companies to provide training related to their devices and also modular pedagogical approaches that allow them to create the adapted content for the type of exercise they want to propose to their students. Some lecturers are willing to train themselves "on the job" through mentored projects provided by companies.

3.1.2. Modernisation of STEM teachers' recruitment and career management

To face the STEM teacher shortage, education authorities are hiring experienced professionals from the industrial sphere. They have a solid background in STEM fields and often bring value to their students by giving them up-to-date case studies. These professionals need to have a special training track to acquire the basics of teaching to integrate successfully into the education system. In AT, Human Resources departments can offer special contracts, especially for IT professionals, who enter the school system to become teachers. In MT, MCAST (Malta College for Arts, Science & Technology) is conducting training in pedagogy for professionals who are being recruited as teachers or lecturers within MCAST. Similarly, the Institute for Education is currently promoting a number of pedagogy courses for professionals who might be interested in changing careers towards teaching.

The STEM talent shortage challenge for European ministries of education has been documented by the European Commission since 2012.[30] According to the last Eurydice report on teaching careers in Europe,[31] most European countries are facing this shortage, although the intensity varies among European sub-regions or countries. The "baby boomers' retirement" and the lack of motivation of students for the teaching career, especially in STEM, are the main factors leading to the shortage. This is a critical issue: if governments are not able to hire and train good STEM teachers, the chances of getting STEM graduates will be scarcer and scarcer: promoting STEM teaching careers and finding incentives to address this issue is urgent. Collaboration with the private sector could help in recruiting the needed profiles: at present, the potential of initiatives offering hybrid career paths, from engineering positions in private companies towards teaching positions, seems to be underexploited.

3.2. TRAINING TEACHERS IN NEW METHODOLOGIES THROUGH INNOVATIVE TRAINING SOLUTIONS

With the generalisation of Internet capabilities and the digital economy, new teaching methodologies are emerging, which tend to be used throughout Europe. In FR, teachers can access online platforms for in-service training, like the "Magistère" national system mixing online courses and face-to-face meetings. In HU, the Human Resources Development Operational Programme includes more developments focusing on STEM. It emphasises the development of new inspirational methodology and technology in the fields of STEM to help teachers to engage their students in learning and it also focuses on the development of new methodologies for experiential education programmes. In MT, teachers are encouraged to participate in online training (e.g. webinars, MOOCs [Massive Online Open Courses]), Erasmus+ training, seminars or workshops organised by DLAP (Science Centre) throughout the year. In ES, a new model of teacher training intends to develop massive training opportunities based on open and social learning through activities that generate interaction, aggregated production, shared knowledge and the building of professional networks. Courses are offered in the form of MOOCs, NOOCs (Nano

30 European Commission/Eurydice/Eurostat. "Key data on education in Europe 2005." (2005). https://ec.europa.eu/eurostat/documents/3217494/5666850/NC-AF-05-001-EN.PDF/09eebb67-39c1-4fa1-a590-5fa921aa2eba [Accessed: October 2018].

31 European Commission/EACEA / Eurydice. "Teaching careers in Europe: access, progression and support." (2018). https://eacea.ec.europa.eu/national-policies/eurydice/content/teaching-careers-europe-access-progression-and-support_en [Accessed: July 2018].

Online Open Courses) and SPOOCs (Self-Paced Open Online Courses).

These new methodologies make training capabilities easier to access. European countries seem to have no choice but to build on these new solutions to develop teachers' skills and generalise the faster and wider dissemination of training content they need. Promoting STEM teaching careers among students would also help. These new training opportunities improve the reputation of the teaching profession.

3.3. INNOVATIVE EDUCATIONAL RESOURCES EMPOWER STEM TEACHERS

In addition to the new teaching methodologies for teachers, a pool of innovative material is available either online (for virtual material) or in universities and sciences centres. It helps teachers to develop new teaching methodologies for their courses and content to promote STEM education.

In GR, the e-me Digital Learning Platform is a secure, integrated digital environment for learning, collaborating, communicating and networking for all members of the school community. It addresses pupils and teachers and is essentially an online platform where teachers can upload digital material for their students and for other teachers. The edulab pilot programme supplies 121 schools across the country with an ICT and STEM open laboratory. It includes prototyping (3D printers), robotics equipment (robotics kit) and software (adaptation of mature open-source platforms for class management, content management and school administrative services) among others. All BE (Flemish) STEM activities are compiled on the www.stem.vlaanderen.be STEM Portal (in three sections: education, work and leisure time). Learning materials are developed by education providers, schools and a wide range of service providers. In HU, the GEOMATECH project (launched by the BKF Foundation for Communication, the BKF University of Applied Sciences, among others) is aimed at developing teacher competencies. It provides digital tools and interactive digital educational materials (GEOMATECH system, 3D printing methods and mobile applications) for the classroom. In LT, devices for science and technology laboratories are provided to many schools. Under the project "Technology, Arts and Natural Sciences Infrastructure", 404 schools received equipment, tools, furniture for science, technology and art classrooms.

In the EU, the T³ Europe network of mathematics and STEM teachers offers educators free access to peer reviewed, curriculum-related resources and webinars (www.t3europe.eu).

Beyond traditional training, some countries are proposing alternative ways of increasing the skills of STEM teachers. The logic is reversed. The aim is not to train teachers so that they can better teach STEM afterwards but to get them into demanding projects with their students and support experts to develop their pedagogical STEM skills on the job. The advantages are accelerated development of targeted skills and more motivated teachers, who acquire the right skills at the right time in the right place.

4. A maze of STEM resources

4.1. TEACHERS ARE PRODUCING CONTENT WITH MINISTRIES AS CURATORS

Many teachers are also developers of pedagogical content. This content is usually reviewed by the community and enriched to produce valuable resources for all. Thus, communities are often developed around specific STEM subjects to cooperate and co-construct new content. In AT, the initiative “MINT-3D-Druck” aims to support schools in the use of 3D printers in the classroom to raise interest in STEM (in lower and upper secondary schools). Learning resources are developed by teachers as creative commons and improved by a Wiki-like peer quality system. In GR, the Laboratory Centres of Physical Sciences organise local communities of practice. Also, organisations (i.e. GFOSS) and local universities organise communities for STEM teachers to exchange good practices, educational resources and maintain e-learning platforms (e.g. Moodle) that contain STEM-related Open Educational Resources. In LT, there are plans to create virtual teachers’ communities to update the curriculum: the government is adopting a crowdsourced approach. Teachers have the opportunity to communicate and share good practices in forums such as “Ugdymo Sodas” and on the website of the STEM schools’ network.

In FR, the Tactileo platform (for Physics-Chemistry, Technology and Earth and Life Sciences) offers not only science resources to help teachers construct their courses but also a built-in tool to help them do so. In ES, the Ministry makes available different platforms for teachers who wish to share resources and material that they have created themselves (PROCOMUN). In GR, user-generated content is widely supported through many national educational aggregators for educational content, where teachers can upload self-generated material. In FR, at local authority level, websites by subject are developed to help teachers share their pedagogical productions, resources, local partnerships, etc. There are also specialised websites for each science subject, created in cooperation with the *Ecoles Normales Supérieures*: they give high-level scientific information that could help teachers construct their courses, or design their own personal training. These institutional sites aim to build communities of practices but the dynamics of exchange among teachers on these sites still remains too weak. Teachers still prefer local exchanges or private websites.

In TK, the Education Information Network portal has facilities for STEM teachers to share their STEM project activities and lesson activities (videos, documents, etc.). In GR, all centres (EKFE & KEPLINET) maintain Web pages to support STEM teachers, and social media pages, and promote local programmes, STEM activities, training actions, competitions, etc. In LT, many digital learning resources can be found on the website “Ugdymo Sodas”.

In addition to these websites, governments are trying to improve their education systems by providing a pool of material to support the processes of innovation and teaching reform. In IT, Indire (Instituto Nazionale Documentazione Innovazione Ricerca Educativa) has promoted the development of particular resources for STEM education in the context of its training projects for teachers. More than 800 resources developed for the main STEM subject areas and for different school levels are available in the “Scuolavalore” portal. Among this material, there are reflections and theoretical insights, educational paths, video lessons, concept maps, simulations, tutorials, suggestions to address specific learning difficulties, tests for assessing students' learning and self-evaluation of their courses for teachers. In RO, the Ministry of Education is supporting the development of a national virtual repository (Schools Virtual Library) that will contain every single educational resource obtained by public funding, including European projects. In SK, training institutions that offer STEM courses for teachers publish learning resources. In DK, one of the initiatives in the National Natural Science Strategy focuses on the development of the "Natural Science ABC". This ABC focuses on the main principles of natural science, and is a key framework for teaching and learning natural science at different levels of the education system. A group of experts are developing these principles. In TK, the Ministry of National Education's Directorate General for Innovation and Educational Technologies has prepared the "STEM Education Teacher Handbook" to guide teachers in preparing interdisciplinary projects and developing contents.

As previously mentioned, in EU, the T³ Europe network of mathematics and STEM teachers offers the teacher community free access to peer-reviewed, curriculum-related resources and webinars (www.t3europe.eu)

Content created and shared by teachers on collaborative platforms answers real demand. However, the human and financial resources to support this activity for a long-term period are lacking. The life cycle of productions, including quality assurance, or the remuneration of authors is rarely considered: the unequal quality of resources and the exhaustion of the most committed teachers are realities. To enhance these "crowdsourced" contents and respond to the problems they generate, most European states do significant work in classifying and qualifying resources. This work may remain hidden, as teachers can feel lost in the maze of STEM resources. To promote quality portfolios of resources, few states seem to have a level of investment in marketing and communication comparable to that of private actors or even NGOs. Governments need to redefine their position in this sector if they want to lead and make teachers adopt the numerous guidelines they are issuing.

UNIVERSITY VOICE

Academics are producing their own resources and publishing them on personal websites or internal platforms (Moodle, Blackboard, etc.). Open-source licences are mentioned and copyright issues are growing concerns.

Some lecturers are producing rich multimedia contents, even MOOCs, when there are relevant capacities (studio, partnerships, etc.) available for them. Then, they integrate MOOC in their courses and universities/schools use MOOCs to promote training programmes and recruit students.

UNIVERSITY VOICE

The numerous resources available online need to be quality-controlled by teachers for peers or students. It's a time-consuming activity with the problem of maintaining the database of content (dead links, obsolescence, etc.).

4.2. NGOS AND PRIVATE COMPANIES IN BETWEEN TEACHERS AND INSTITUTIONS ARE PARTICIPATING IN CREATING "STEM COMMONS"

NGOs and private companies are investing in the development of the STEM education sector. One of the initiatives to accelerate the adoption of new methodologies and new training practices could be the construction of a complete open ecosystem where everyone, including government and teachers, could cooperate and develop more valuable material. There are already some initiatives conducted in Europe, e.g. in PT, with the "Teachers Try

Science" Project, developed through a partnership between the Ministry of Education and IBM. STEM learning communities have been created so that teachers of different education levels, from pre-school to lower secondary, can share resources, experiences and good practices. In PT again, as part of the STEM projects, resources are developed via online platforms. Corporate partnerships are created to secure funding and to assure the sustainability of STEM-related learning resources.

In ES, the Ministry usually collaborates with private organisations, such as Samsung, to develop innovative educational projects (Samsung Smart School programme). In addition, other agreements have been signed for the development of a Future Classroom Lab on the premises of INTEF with the support of private partners. In GR, in collaboration with the Institute of Educational Policy, the Ministry of Education supports actions, programmes, competitions offered by non-profit organisations, universities, educational associations, etc., aimed at the development of STEM education. Their cooperation with industry for the contextualisation of STEM education to develop more appropriate learning resources is based on an open framework. Schools develop individual programmes involving industry contacts to publish learning resources and gain expertise. In MT also, the Ministry of Education supports the ongoing development of STEM education learning resources by liaising with industry partners: the Ministry guarantees the relevance and validity of contents.

At the European level, some programmes are based on cooperation between ministries and companies or NGOs. The STEM Alliance initiative – operating several initiatives such as "STEM discovery week" – benefits from the support of more than a dozen private companies. This type of cooperation is key especially for some advanced technological STEM areas: private companies are providing up-to-date devices and industrial materials to train teachers and students in high schools and higher education. The T³ Europe network of mathematics and science teachers have also developed the TI STEM Lab Network, a group of general and vocational secondary schools across Europe with a strong profile in STEM education. It is a platform for collaboration where teaching and learning content is developed, evaluated and shared for adoption in everyday classrooms.

NGOs and private companies are establishing partnerships with governments to act around STEM. Some private companies provide equipment, materials, STEM content, training sessions, mentoring, etc. to schools. Some of these resources are crucial because they relate to the most recent industrial processes. The creation of educational resources for teaching STEM no longer relies solely on the activity of traditional publishers or public-funded publishers operated by ministries. New business models allow NGOs and private companies to create quality content adopted by teachers. This transition to free supply of resources is observable in several European countries and encouraged by European Commission-funded programmes.

UNIVERSITY VOICE

Academics are using pedagogical materials (devices, documents, videos, etc.) provided by private companies but student are suspicious. They don't want to specialise too much in one type of products and prefer open platforms (Arduinos or equivalent) or market leaders' platforms with a lot of content (code libraries, project documents, video tutorials, etc.) already available.

UNIVERSITY VOICE

Technical engineering training programmes (analog design engineer, electro-technical engineer, etc.) have one point in common: they depend on the availability of a broad range of specific hardware that is subject to accelerated obsolescence (especially at Master's level). The purchase policy and partnership policy of the organisation (university, engineering schools) has an impact on the type of courses and exercises that lecturers are able to offer to their students; the purchase policy of high schools has also an impact on the skills developed by future students (existence of rich sciences labs and appropriate devices in high schools); there is no such issue for the software engineering training programmes due to the greater modularity of computers.

Conclusion

This *STEM education policies in Europe* study presents a synthetic description of the context and an overview of the main national level initiatives aimed at addressing particular STEM challenges. The information included in this report was collected via a survey completed by the Ministry of Education STEM representatives of 14 countries, who were invited to describe the current STEM education strategies in their countries, and to provide information about ongoing national initiatives. This data was complemented by information collected through a number of interviews with stakeholders from adjacent sectors (industry or higher education).

Through consultations with Ministry of Education representatives and industry and university stakeholders, a number of STEM education challenges were identified. Potential pathways for overcoming these challenges were also proposed:

1. Attracting more students and teachers to STEM education through a global approach from primary education to continuing professional development that will better anticipate the skills needed for the society of the future;

2. Breaking the barriers between subjects with pragmatic initiatives (teacher training sessions, publishing contents, sharing best practices, etc.) to improve the quality of STEM education by building on each country's strengths;

3. Evaluating and integrating curriculum and pedagogical innovations: all energies must be oriented in the right direction with value added purpose-built technologies and services that need to be provided; positive experimentations need to be rolled out across the entire education system and disseminated among European countries (sharing of best practices, ideally in line with a common European framework);

4. Developing a common European framework of reference for STEM education and coordinating national STEM initiatives related to publishing pedagogical content to ensure teachers' needs are met;

5. Fostering deeper collaboration with universities and industry to develop STEM teachers' skills.

One of the main motivations for improving STEM education is the need to attract more students into STEM studies to provide the job market with adequate resources, in terms of quality and quantity. However, this motivation lacks a coherent and integrated approach:

a. some countries are focusing on ICT for primary and secondary education, mainly coding projects (designing games, programming robots, etc.), which do not necessarily develop skills related to research and development activities that an engineer would require;

b. the well-known fact that employers depend on universities that in turn depend on high schools to recruit STEM skilled candidates does not seem to inspire national STEM strategies, which involve an ambitious cooperation between these three types of actors.

There are silos and boundaries that segment the STEM block of subjects, especially between mathematics and sciences. Mathematics is prevalent in the STEM block – failure in this field is not an option for students who want to embrace STEM careers – but innovative and engaging pedagogical approaches seem to be developing faster in other STEM subjects. Sharing best practices between STEM courses should increase the quality of STEM teaching as well as the commitment and success of students in these paths, but it is a challenge to develop transversal approaches in teacher training and content publishing.

A truly harmonised national approach must be put in place to coordinate numerous and diverse partnerships or internal programmes in favour of STEM. STEM initiatives should be connected to the curriculum or fully integrated into schools' local strategies for measuring their impact on student success and therefore their overall efficiency. A "what works centre" on STEM initiatives and programmes is needed to study the major initiatives of this burgeoning sector and scale up those that impact positively. While a variety of approaches is needed, the lack of a coordinated approach also appears when one looks at the heterogeneous partnerships between high schools and universities and companies.

The creation of educational resources for teaching STEM no longer relies solely on the activity of traditional publishers. A trend has emerged where teachers themselves develop resources and share them with specialised communities. On the other side, NGOs and private companies are beginning to offer quality content that teachers adopt. This transition to a large supply of resources is observable in several European countries and encouraged by European Commission-funded programmes. Choosing between a diversity of STEM teaching resources available can prove challenging for teachers. Public stakeholders have not yet reacted adequately to this new situation: curation is not sufficient and a national content strategy should be implemented to define roles and responsibilities for the numerous actors concerned.

To develop STEM teachers' skills, governments could increase the involvement of universities and deepen partnerships with companies. University staff do not always feel sufficiently recognised when they participate in promoting STEM academic paths. Partnerships with private companies do not seem to be structured to take account of local stakeholders' points of view, although these private companies are the ones who are industrialising new technologies that will affect both teaching and learning. It is essential to define models and best practices on a European scale to generalise faster and wider dissemination of the training content needed by teachers. Governments could also use innovative propositions such as on-the-job training, mobile learning and micro-certifications. These new methodologies make training capabilities easier to access.

These five points reveal a major strategic issue. While European countries participating in the study have described their ambitions and actions regarding STEM education, it is difficult to observe at present the implementation of an integrated strategy involving all the domains and actors concerned on a national or European scale. Of course, more data will become available as the STEM plans that are presently being developed in many countries (France, Germany, Italy, etc.) are fully implemented.

To cope with the fast pace of technological innovation, European education systems need a better vertical integration of their STEM policies with better relations between schools, universities and companies recruiting STEM profiles. Researchers are developing new paradigms and technologies, companies are industrialising these discoveries: both are activities based on new devices and skills sets that teachers must master and convey to their students to prepare them for the job market.

European education stakeholders also need better horizontal integration to develop a balanced approach between the different parts of the STEM block to ensure that:

- the emphasis on ICT skills in primary and secondary education does not marginalise other STEM skills such as engineering;
- students' difficulties in mathematics do not negatively affect their motivation for experimental scientific inquiries;
- students or teachers are able to transition between different STEM domains to tackle scarcity issues locally or in specific STEM domains;
- industry develops education purpose-built technologies and services helping the academic world to acquire the skills needed to be competitive on the job market and fill the gap in STEM-related jobs currently foreseen.

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Country codes

CODE	COUNTRY
AT	Austria
BE	Belgium
DK	Denmark
ES	Spain
FR	France
GR	Greece
HU	Hungary

CODE	COUNTRY
IT	Italia
LT	Lithuania
MT	Malta
PT	Portugal
RO	Romania
SK	Slovakia
TK	Turkey

Acknowledgements

We would like to thank the European Schoolnet Ministry of Education STEM representatives from Austria, Belgium (Flanders), Denmark, France, Greece, Hungary, Italy, Lithuania, Malta, Portugal, Romania, Slovakia, Spain and Turkey for their valuable contributions in providing relevant information from their countries and in reviewing and providing feedback on the overall report, as well as to all the company and university representatives who participated in the interviews.

SCIENTIX
The community for science education in Europe

This "Science, Technology, Engineering and Mathematics Education Policies report" is a Scientix Observatory publication from Scientix, the community for science education in Europe with the support of Texas Instruments. The present report is the first in a series of investigations into STEM education policies and practices in Europe. Its aim is to provide the context for further investigation into the way educators throughout Europe are organising their STEM teaching. The second publication of the series – the Science, Technology, Engineering and Mathematics Education Practices report – to be published in December 2018, will draw on the results of a large-scale European survey on teaching and learning practices in the fields of Science, Technology, Engineering and Mathematics education. Its aim is to shed light on the current state of affairs in STEM education and to contribute to a better understanding of how STEM subjects are being approached in schools in Europe, and what teachers' needs are in terms of training, access to resources and technical support.

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The work presented in this document is supported by the European Commission's H2020 programme – project Scientix 3 (Grant agreement N. 730009), 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.