
DELIVERABLE REPORT

# D2.2 STEM QUALIFICATION AND JOB PROFILES REPORT

M20, DECEMBER 2017

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ENJOY. SCIENCE TECHNOLOGY ENGINEERING MATHEMATICS.

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# List of abbreviations

AAGR: Annual Growth Rate
ASPIRES: Accelerating Strategies for Practical Innovation and Research in Economic Strengthening
AU: Austria
BE: Belgium
BG: Bulgaria
BIM: Building Information Modelling
CAO: Chief Analytics Officer
CEDEFOP: European Centre for the Development of Vocational Training
CZ: Czech Republic
CY: Cyprus
DE: Germany
DK: Denmark
EE: Estonia
EL: Greece
ES: Spain
FI: Finland
FR: France
GVCs: Global value chains
HR: Croatia
HRST: Human resources in science and technology
HU: Hungary
IE: Ireland
ICT: Information and communications technology
ILO: International Labour Organization
IoT: Internet of Things
IRR: Internal Rate of Return
ISCED: The International Standard Classification of Education
ISCO: International Standard Classification of Education
IT: Italy
KET: Key Enabling Technologies
LT: Lithuania
LU: Luxembourg
LV: Latvia
MRE: Marine renewal energy
MT: Malta
NL: Netherlands
NPV: Net Present Value
PL: Poland
PT: Portugal
RO: Romania
SCCT: Social cognitive career theory
SOC: Standard Occupational Classification
SE: Sweden
SI: Slovenia
SK: Slovakia
UK: United Kingdom

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# *EXECUTIVE SUMMARY*

**STEM programs from the world's leading universities offer a rich, varied and interdisciplinary education.** Undergraduate programs in STEM fields often require courses such as Entrepreneurship, Business, Ethics, Reading and Composition skills. Many top-level universities also offer dynamic Science, Technology, and Society undergraduate programs, where STEM is combined with other fields, based on the premise that problems in the global context are simultaneously scientific and social, technological and political, ethical and economic.

**Pedagogical research seems to prove that interest in STEM must be created and enhanced in primary and secondary school**. Providing pupils with a clear insight of what a STEM career consists of and implicates can be very helpful to capture their attention and curiosity and shape an interest in STEM subjects. STEM extra-curricular activities are significantly more effective in increasing the amount of STEM pupils than further work in the classroom. Governments, through educational institutions and agencies, have paid considerable attention to enhance online teachers training in various forms that can indirectly be helpful to raise young people interest in STEM subjects.

**Most European countries consider STEM education a priority.** To address this priority, some have elaborated strategies at a national level, while others do not have a unique strategy but more varied ones. STEM curricula should be strongly enhanced both at primary and secondary level. To become more attractive for student, STEM education should undergo some rearrangements as to content and method. The core of new teaching should be inquiry-based, with a strong emphasis on socio-economic aspects of science. European agenda insists on the prominence of the concept of Responsible Research and Innovation (RRI) for STEM education and on the necessity to make it part and parcel of teachers and pupils formation.

**In the period 2015-2025, there will be 8.2 million new STEM jobs in the EU.** STEM professionals will probably be more sought after than STEM associate professionals. Future growth in STEM employment is likely to be unevenly distributed across EU Member States. Austria, Sweden, Slovenia, and Malta will enjoy a growth of S&E professionals. In Finland, France, Germany, Hungary, Italy, Luxembourg, Portugal, employment of S&E and ICT professionals is likely to increase. At the same time, Germany and Hungary are expected to have a drop in employment of associate professionals, and so are Bulgaria, Lithuania and Romania. Employment will increase to at least a certain extent across all STEM occupations in Denmark, Spain, Czech Republic, Ireland and Luxembourg.

**The skills profiles of STEM workers will need to adapt on the developments and trends of the industries they work for**. In addition to industry-specific trends, a

number of cross-sectoral factors could further shape the demand for STEM workers. Such trends include automation, the Big Data trend, cloud computing, Internet of Things (IoT), new production processes (Industry 4.0), a growing demand for interoperability, standardization, and new threats from cybercrime and cyberterrorism. Finally, many of the STEM job openings in 2025 will be a consequence of replacement demand.

**If not enough students will enrol or graduate from STEM degrees, supply will not meet the rising demand for STEM professionals (shortage scenario).** Universities will face the challenge of not providing enough graduates to cover the labour demand in the STEM sector. This fact might be due to a low enrolment and drop-outs. Universities could then promote a positive image of STEM sciences, lower the intensity of educational demands, or increase cooperation with stakeholders (industry, schools, government). At the same time, the private sector would face a lack of employees. Recommendations include involvement in the education process, improvement of employment conditions, and a clearer communication of industry needs. The government, among others, would face companies relocating away to countries with higher STEM supply.

**Even if there were just as many STEM jobs as STEM graduates, problems could still arise (equilibrium scenario).** Employers might have hard time finding the specific profiles they look for, for example in terms of soft skills, working experience, or management skills. Firms should maintain solid connection with universities, and facilitate work-life balance to ease female uptake. Universities would struggle to adapt their curricula to changing firm needs and to widen the scope of STEM fields. They should include non-STEM training in their curricula, increase openness to society and combine STEM degrees with other departments. Furthermore, equilibrium could disappear anytime and in any direction. The public sector would need to be prepared to act in the event of any market imbalance, for example by promoting STEM among the general public, or to involve STEM experts in education policy making.

**If the supply of STEM skills exceeded the number of available STEM jobs, many STEM graduates would not be able to find an appropriate employment (surplus scenario).** Universities face the challenge of adapting to a inevitably changing labour market. They could provide students with business skills, to increase employability, entrepreneurship skills to help them starting their own business, or offer interdisciplinary degrees. The private sector would apparently enjoy an ideal position, as it would count on a large pool of graduates from which to recruit. However, this might affect the industry's ability to compete in the global market.  They could contribute to improve employability, for example by increasing apprenticeships and graduate programs. The government would face the great challenge of high-skilled unemployment, or of skills mismatch. The private sector could back seed and startup capital, and foster innovation. Another action could be a legislation upgrade that

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accounts for the changing economic context, or a yearly review of universities to assess teaching schemes and to take into account global trends.

# 1 INTRODUCTION

The aim of this report is to describe how well the EU is prepared to meet future STEM skills requirements. The present document represents deliverable D2.2 of the STEM4YOUTH project funded under H2020. It summarizes and presents the result of Task T2.1 “Analysis of Supply and Demand Side of STEM”, T2.2 “Development and validation of the scenarios and trends”, and T2.3 “Definition of educational profiles addressing the labor market needs”. Chapter 2 provides an overview of the overall research design and methodology used throughout the study, and the relation with the other WPs. A systematic literature review was undertaken to set a background for the research. Evidence was corroborated through data analysis from official statistics, policy reports and grey literature, as well from the analysis of curricula from STEM leading schools. A number of in-depth interviews to European employers have been carried out to better depict the demand side of STEM skills. Finally, a validationn workshop with STEM stakeholders was organized to develop and analyse potential scenarios for the future STEM labour market, as well as to provide recommendations. Chapter 3 explains how the market for STEM skills is likely to evolve in the future, using CEDEFOP projections of STEM employment until 2025. It also considers those STEM skills that are likely to be most in demand, given industry and society trends, and presents some insights from in-depth interviews. Chapter 4 presents innovative practices and initiatives in place to foster the STEM uptake, gathering results from the curricula analysis and the scoping review. Finally, Chapter 5 aims at defining how prepared is the EU to meet such future STEM skills requirements and presents the validation workshop outputs, defining challenges and recommendations for universities, industry and the government.

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# 2 Methodology

This chapter presents the overall logical framework for WP2, along with a detailed description of the different methods used throughout the realization of this deliverable, and the relation with the other WPs.

## 2.1 Background: on mixed methods

Qualitative research has been the object of a long and controversial debate (Bryman, 2006; Dezin & Lincoln, 2005) possibly due to the difficulty to establish its own distinctively peculiar "language" and "truths". While quantitative research has become the language of research because of its success, it has been difficult to establish an independent qualitative language of research with its own developed concepts about the "trinity of truth": reliability, validity, and generalisation. Whereas the more radical supporters of the qualitative approach argue that the assessment of the quality of qualitative data should transcend conventional standards (i.e. reliability, validity, generalisation), several scholars hold that external confirmation of qualitative findings through well designed purposive sampling checking and methods/sources triangulation can enhance the credibility and validity of qualitative research (Bryman, 2006; Denzin & Lincoln, 2005; Miles & Huberman, 1994; Seale & Silverman, 1997). While pure qualitative approaches are still pursued, since the 1990s a new consensus emerged about the complementary relationship between qualitative and quantitative perspectives that recognizes the different utilities of each for a researcher.

Studies that combine both qualitative and quantitative methods are becoming more and more common (Brannen, 1992; Bryman, 1988, 2004; Bryman, 2006; Cresswell, 2007; Creswell, 2003; Tashakkori & Teddlie, 2003). In this sense, we end up with three distinct approaches to research: quantitative; qualitative; and what is variously called multi-methods (Brannen, 1992), multi-strategy (Bryman, 2004), mixed methods (Creswell, 2003; Tashakkori & Teddlie, 2003).

Our research design, data gathering, and analysis are based on a **mixed methods approach** where we triangulate different methods/instruments and sources. As suggested in the editorial (Veltri et al., 2014) to the special issue that the journal "Innovation: The European Journal of Social Science Research" has recently developed on the topic, qualitative and mixed methods research can contribute to "evidence-based" policy in a number of ways depending on the purpose for which the research is launched. Green et al (1989) through a systematic review, later replicated and fully confirmed by Bryman (2006), identified five justifications used by scholars combining quantitative and qualitative methods and sources in mixed approaches:

1. **Triangulation**: convergence, corroboration, correspondence of results from different methods. In triangulation the emphasis is placed on seeking corroboration between quantitative and qualitative data.
2. **Complementarity**: re-elaboration, enhancement, illustration, clarification of the results from one kind of source/method with the results from another kind of source/method;
3. **Development**: using the results from one method to inform the other method (i.e. typically qualitative research such as focus groups conducted as preparatory of quantitative surveys)
4. **Initiation**: seeking the discovery of paradox and contradiction, new perspectives, the recasting of questions or results from one method with questions or results from the other method;
5. **Expansion**: extending the breadth and range of enquiry by using different methods for different inquiry components

## 2.2 Overall design and relations with other WPs

In his review Bryman (2006) found that **triangulation and complementarity** are the main justifications used by scholars adopting mixed methods approaches. Triangulation and complementarity are also the main reasons why we used different methods and sources in this WP2. More in detail, we have translated WP2 tasks and objectives as envisaged in the proposal into the following overarching research question:

*How well is the EU prepared to meet future STEM skills requirements?*

This provided us with a starting point for the operationalisation of our tasks. In turn, we have specified our research question into the following four sub-questions:

- *RQ1: What is the extent and nature of the EU labour market for STEM skills?*
- *RQ2: Which factors affect the EU supply of STEM skills?*
- *RQ3: To what extent do innovative practices prepare students with STEM skills? What are the main initiatives to foster STEM skills in the EU?*
- *RQ4: How is the EU market demand for STEM skills likely to evolve in the future, and which STEM skills will likely be most in demand?*

Findings for the first two sub-questions (RQ1 and RQ2) are reported in Deliverable D2.1 “Report on employment labour market trends in EU”, while findings for third and the fourth sub-questions (RQ3 and RQ4) are reported in Deliverable D2.2 “STEM qualification and job profiles report”.

Each of the four sub-questions was answered through a mixed-methods approach, following the principles of triangulation and complementarity. The following five methods were used during the work:

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- A systematic **literature review,** to set an overall background;
- Quantitative **data analysis** from official statistics (such as Eurostat) to describe and summarize trends in the EU labour market for STEM skills;
- A **curricula analysis** to describe innovative initiatives as well as key features of leading STEM departments;
- In-depth **interviews** to employers, to understand demand-side barriers;
- A **validation workshop**, to understand supply-side barriers and to develop recommendations.

Each method was used to target one or more research sub-questions. The following figure sketches the methodologies that were used in each sub-question.

*Table 1 Methodological overview - How well is the EU prepared to meet future STEM skills requirements?*

| | Desk research | | | Field research | | |
|---|---|---|---|---|---|---|
| | Systematic review | Data analysis | Curricula analysis | In-depth interviews | Validation workshop | |
| *RQ1: What is the extent and nature of the EU labour market for STEM skills?* | | √ | | √ | | **D2.1** |
| *RQ2: Which factors affect the EU supply of STEM skills?* | √ | | | | | |
| *RQ3: To what extent do innovative practices prepare students with STEM skills? What are the main initiatives to foster STEM skills in the EU?* | √ | | √ | | √ | **D2.2** |
| *RQ4: How is the EU market demand for STEM skills likely to evolve in the future, and which STEM skills will likely be most in demand?* | √ | √ | | √ | √ | |

WP2 is a self-standing work package. However, it is set to contribute to the work of the project, especially with regards to WP3, WP5, WP6, and WP9. More in detail, findings from RQ2 inform the development of methodologies and educational tools (T3.3), while findings from the literature review used to answer to RQ3 benefits from synergies with and is strictly related to the analysis of methodologies and tools (T3.1). The supply and demand analysis conducted for RQ1, and the forecast in the context of RQ4, feed into the development of the content, tools and learning methodology (WP5), and are set to be included in the OLCMS (WP6). Finally, the findings presented in D2.1 and D2.2

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contribute to the overall communication of the project, and are contained in the diffusion material developed and shared in the context of WP9.

In the remainder of this chapter, each of the five methods used is described in detail, with particular regard to information collection, processing and analysis.

## 2.3 Specific methods

### 2.3.1 Systematic literature review

Our systematic literature review has been aimed at answering the following research sub-questions:

- *RQ2: Which factors affect the EU supply of STEM skills?*
- *RQ3: To what extent do innovative practices prepare students with STEM skills? What are the main initiatives to foster STEM skills in the EU?*
- *RQ4: How is the EU market demand for STEM skills likely to evolve in the future, and which STEM skills will likely be most in demand?*

The review also contributed setting a background for our research, and screened the body literature existing on the matter, by combining studies on supply and demand and studies specifically focused on other aspects concerning STEM, such as gender studies or program evaluations. In this literature review, a structured approach to find and choose the relevant articles was applied. This selection had to be not too broad, so as to have manageable number of papers, and not too restricted, so as to include all the existing relevant evidence. If the review was exclusively focused on a European context, too few results would have been obtained and an important part of the literature would have been missed out accordingly. Therefore, we included evidence from third countries.

The selection of the relevant articles followed three steps:

1. Setting up the scope, the search string, and the inclusion criteria;
2. Creating the database, identifying studies;
3. Selecting the studies to be included in the review.

We defined the scope of the review using the PICOC model: Population, Intervention, Comparison, Outcomes, Context. The population of the study is the EU, where applicable. Interventions are initiatives to encourage the uptake of STEM disciplines, whereas Comparison is not applicable in this case. Outcomes are different variables, such as enrolments, graduations, or dropouts; subjects; Context is STEM skills. However, for the systematic review we broadened the scope in order to have a richer insight of the literature. After several calibrations, the following search string was used with Boolean operators:

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*(STEM OR (science AND technology AND engineering AND (mathematics OR maths))) AND (skills OR competencies OR supply OR degree OR graduate OR university OR school OR college OR (higher AND education) OR learning OR curricula OR student) AND (jobs OR (job AND placement) OR employment OR career OR demand OR workplace OR labour OR labor).*

We introduced some variations in the search string to check how this modified our results. For example, if we did not include the words "school" or "university", relevant papers disappeared. On the other hand, if we only used the most relevant words such us "skills", "supply", "demand" or "higher education", the number of results increased dramatically and most of the papers deviated notably from the objective of this study. Therefore, we concluded that the previous search string was the most suitable.

Our inclusion criteria were documents written in English and no older than 2000. Using these criteria and the search string, we conducted the search in October 2016 in five electronic databases: EconLit (ProQuest XML), Emerald Management Xtra 111, IDEAS – RePEc (Research Papers in Economics), ISI Web of Science, and Scopus. The following table provides an overview of the data sources.

*Table 2 Database overview*

| Source | Description |
| --- | --- |
| **EconLit (ProQuest XML)** | It is a bibliographic database published by the American Economic Association. It offers access to bibliographic information and abstracts of journal articles, monographs, dissertations, working papers and reviews of documents published in specialized economics and business journals. It covers topics such as accounting, economic policy, labour, marketing economic theory, etc. |
| **Scopus** | Scopus is the largest abstract and citation database of peer-reviewed literature: scientific journals, books and conference proceedings. It delivers a comprehensive overview of the world's research output in the fields of science, technology, medicine, social sciences, and arts and humanities. |
| **ISI Web of Science** | It provides access to the world's leading citation database, with multidisciplinary information from over 12,000 high impact journals and over 160,000 conference proceedings from around the world. |
| **IDEAS – RePEc (Research Papers in Economics)** | It is the largest bibliographic database dedicated to Economics and available freely on the Internet. It includes over 1,700,000 items of research. About 1500 institutions contribute their bibliographic data directly to this database. |

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| **Emerald Management Xtra 111** | Emerald is a global publisher linking research and practice to the benefit of society. The company manages a portfolio of over 295 journals and over 2,500 books and book series volumes. The database gives access to some of these documents. |

The search provided 2183 results. A preliminary screening of the results revealed that many articles were not relevant and the number went down to 824. In order to narrow the number of articles, the most relevant among them were selected through the screening of the abstracts. This restriction was aimed at finding papers closely related to STEM to create the final database. After introducing these restrictions, the following step was to check that articles were not repeated within the and among databases. The number of papers decreased to 287.

In the analysis, it became soon clear that the literature provides little systematic evidence on demand and supply of STEM-skilled professionals. Therefore, we validated this list through the integration with **reference and manual desk research on grey literature, administrative sources, policy documents and reports**, to maximize the results. Such literature was screened at the national, EU, and international levels through conventional Internet search engine capabilities.

### 2.3.2 Data analysis

Our data analysis targeted the following two sub-questions:

- *RQ1: What is the extent and nature of the EU labour market for STEM skills?*
- *RQ4: How is the EU market demand for STEM skills likely to evolve in the future, and which STEM skills will likely be most in demand?*

Official statistics (OECD, Eurostat, Cedefop) were consulted and analysed to portrait the main features of the EU labour market for STEM skills, in terms of supply (meant as education) and demand (meant as employment), as well as the forecast of demand for STEM skills up to 2025.

#### *2.3.2.1 Supply*

The present study defines the supply of STEM skills in terms of education level and field, in line with international standards, and subject to data availability. According to the OECD Canberra Manual (OECD, 1995), whose recommendations are followed on the Eurostat domain, human resources "devoted to science and technology" (HRST) are people who either

- have successfully completed a tertiary level of education;
- do not formally qualify as above, but are employed in occupations where such qualifications are normally required.

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Levels and fields of education are here defined according to the European Classification of Fields of Education and Training[1], adapted from International Standard Classification of Education (ISCED). Developed by UNESCO in the 1970s, ISCED is the reference international standard for organising education by level and field. It forms part of the UN International Family of Economic and Social Classifications[2]. With respect to levels of education, a tertiary education corresponds to: Short-cycle tertiary education (ISCED 5); Bachelor's or equivalent level (ISCED 6); Master's or equivalent level (ISCED 7); or Doctoral or equivalent level (ISCED 8).

With respect to fields of education, where possible, a narrow definition has been applied in the present study. The following two-digit codes are considered here as **STEM fields**:

4. Life science (EF42)
5. Physical science (EF44)
6. Mathematics and statistics (EF46)
7. Computing (EF48)
8. Engineering and engineering trades (EF52)
9. Manufacturing and processing (EF54)

Other fields, such as Architecture and Building (EF58) or Health (EF72) are sometimes included in STEM studies using broader definitions (e.g. EU Skills Panorama, 2014). The following table shows all STEM fields of study here considered at a three-digit level of detail.

*Table 3 STEM fields of study*

| ISCED category (2-digit) | ISCED category (3-digit) | Code | ISCED Name |
|---|---|---|---|
| Science, mathematics and computing (EF4) | Life science (EF42) | **EF421** | Biology and biochemistry |
| | | **EF422** | Environmental science |
| | Physical science (EF44) | **EF440** | Physical sciences (broad programmes) |
| | | **EF441** | Physics |
| | | **EF442** | Chemistry |
| | | **EF443** | Earth science |
| | Mathematics and statistics (EF46) | **EF461** | Mathematics |
| | | **EF462** | Statistics |
| | Computing (EF48) | **EF481** | Computer science |
| | | **EF482** | Computer use |
| Engineering, manufacturing | Engineering and engineering trades (EF52) | **EF520** | Engineering and engineering trades (broad programmes) |
| | | **EF521** | Mechanics and metal work |

[1] Europa - RAMON - Classification Detail List. Available at http://ec.europa.eu/eurostat/ramon/nomenclatures/index.cfm?TargetUrl=LST_NOM_DTL&StrNom=CL_FIELD99&StrLanguageCode=EN&IntPcKey=&StrLayoutCode=HIERARCHIC (retrieved 31 October 2016).

[2] United Nations Statistics Division - Classifications Registry.Available at http://unstats.un.org/unsd/class/family/default.asp (retrieved 31 October 2016).

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| | | | |
|---|---|---|---|
| **and construction (EF5)** | | **EF522** | Electricity and energy |
| | | **EF523** | Electronics and automation |
| | | **EF524** | Chemical and process |
| | | **EF525** | Motor vehicles, ships and aircraft |
| | Manufacturing and processing (EF54) | **EF540** | Manufacturing and processing (broad programmes) |
| | | **EF541** | Food processing |
| | | **EF542** | Textiles, clothes, footwear, leather |
| | | **EF543** | Materials (wood, paper, plastic, glass) |
| | | **EF544** | Mining and extraction |

The reference classification framework used here is ISCED-2011. It is worth noting that a more recent classification framework, namely ISCED-F 2013, has been published. However, to date ISCED-F 2013 has not been implemented in EU data collection by Eurostat[3] and therefore does not apply to the present study. The following table shows the correspondence between the two frameworks (UNESCO, 2014).

*Table 4 STEM fields of study, ISCED-F 2013 and ISCED 2011 correspondence table*

| ISCED-F 2013 | ISCED 1997 (and 2011) Fields of Education |
|---|---|
| 051 Biological and related sciences | 42 Life sciences minus other allied sciences |
| 052 Environment | Part of 42 Life sciences (other allied sciences), part of 62 Agriculture, forestry and fishery (natural parks, wildlife) |
| 053 Physical sciences | 44 Physical science |
| 054 Mathematics and statistics | 46 Mathematics and statistics |
| 061 Information and Communication Technologies | 48 Computing |
| 071 Engineering and engineering trades | 52 Engineering and engineering trades (plus most of 85 Environmental protection) |
| 072 Manufacturing and processing | 54 Manufacturing and processing |

*Source: UNESCO Institute for Statistics, 2014*

#### 2.3.2.2 Demand

To define STEM jobs, this study uses the current International Standard Classification of Occupations (ISCO-08) as its main reference. One of the International Labour Organization (ILO) classification structures for organizing information on jobs[4], ISCO-08 forms part of the UN International Family of Economic and Social Classifications[5]. A different classification used in the literature to define STEM jobs (Koonce et al., 2011) is the US Standard Occupational Classification (SOC-10), whose national variations are used

[3] International Standard Classification of Education (ISCED) - Statistics Explained. Available at http://ec.europa.eu/eurostat/statistics-explained/index.php/International_Standard_Classification_of_Education_(ISCED) (retrieved 31 October 2016).

[4] International Labour Organization (ILO). International Standard Classification of Occupations (ISCO), Summary of Major Groups. Available at http://www.ilo.org/public/english/bureau/stat/isco/isco88/publ4.htm (retrieved 31 October 2016).

[5] United Nations Statistics Division - Classifications Registry.Available at http://unstats.un.org/unsd/class/family/default.asp (retrieved 31 October 2016).

in countries such as Spain[6] and the United Kingdom[7]. Although the ISCO-08 differs from the SOC-10, both systems classify occupations based on the type of work performed, and crosswalks between the two have been performed[8].

The ISCO-08 system defines the broad group of **professionals** as "*occupations whose main tasks require a high level of professional knowledge and experience*" such as "*increasing the existing stock of knowledge, applying scientific and artistic concepts and theories to the solution of problems, and teaching about the foregoing in a systematic manner*" (ISCO-08 major group 2). The group of **technicians and associate professionals** includes "*occupations whose main tasks require technical knowledge and experience" such as "carrying out technical work connected with the application of concepts and operational methods in the above-mentioned fields, and in teaching at certain educational levels*" (ISCO-08 major group 3).

Within these two broad groups, two-digit and three-digit codes increase the level of detail in occupations. Earlier EU-level work (OECD, 1995; Goos et al., 2013; EU Skills Panorama, 2014; European Commission, 2015) agree in defining STEM occupations as including some or all of the following categories: Science and Engineering Professionals (ISCO-08-21); Health Professionals (ISCO-08-22); Information and Communications Technology Professionals (ISCO-08-25); Science and Engineering Associate Professionals (ISCO-08-31); Health Associate Professionals (ISCO-08-32); Information and Communications Technicians (ISCO-08-35). The following table offers a comparison of three-digit categorizations of STEM occupations as used in the past and in the current study.

*Table 5 Comparison of STEM occupation definitions*

| Code | ISCO-08 Name | EC 2015 | EU Skills Panorama 2014 | OECD 1995 | Goos et al. 2013 | Current study |
|---|---|---|---|---|---|---|
| **211** | Physical and Earth Science Professionals | | | | | |
| **212** | Mathematicians, Actuaries and Statisticians | | | | | |
| **213** | Life Science Professionals | | | | | |
| **214** | Engineering Professionals (excluding Electrotechnology) | | | | | |
| **215** | Electrotechnology Engineers | | | | | |
| **216** | Architects, Planners, Surveyors and Designers | | | | | |
| **221** | Medical Doctors | | | | | |

[6] INEbase _ Clasificaciones _ Clasificación Nacional de Ocupaciones 1994. Available at http://www.ine.es/clasifi/cnoh.htm (retrieved 31 October 2016).

[7] Standard occupational classification (SOC) - Office for National Statistics. Available at https://www.ons.gov.uk/methodology/classificationsandstandards/standardoccupationalclassificationsoc (retrieved 31 October 2016).

[8] Crosswalks between the 2010 SOC and systems used by other Federal and international statistical agencies. Available at http://www.bls.gov/soc/soccrosswalks.htm (retrieved 31 October 2016).

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| | | | | | | |
|---|---|---|---|---|---|---|
| **222** | Nursing and Midwifery Professionals | | | | | |
| **223** | Traditional and Complementary Medicine Professionals | | | | | |
| **224** | Paramedical Practitioners | | | | | |
| **225** | Veterinarians | | | | | |
| **226** | Other Health Professionals | | | | | |
| **251** | Software and Applications Developers and Analysts | | | | | |
| **252** | Database and Network Professionals | | | | | |
| **311** | Physical and Engineering Science Technicians | | | | | |
| **312** | Mining, Manufacturing and Construction Supervisors | | | | | |
| **313** | Process Control Technicians | | | | | |
| **314** | Life Science Technicians and Related Associate Professionals | | | | | |
| **315** | Ship and Aircraft Controllers and Technicians | | | | | |
| **321** | Medical and Pharmaceutical Technicians | | | | | |
| **322** | Nursing and Midwifery Associate Professionals | | | | | |
| **323** | Traditional and Complementary Medicine Associate Professionals | | | | | |
| **324** | Veterinary Technicians and Assistants | | | | | |
| **325** | Other Health Associate Professionals | | | | | |
| **351** | ICT Operations and User Support Technicians | | | | | |
| **352** | Telecommunications and Broadcasting Technicians | | | | | |

As the groups of health professionals and associate professionals fall beyond the scope of the current study, they are therefore excluded from the analysis. For this study, the following four two-digit ISCO-08 categories define **STEM occupations**:

- 21 Science and Engineering Professionals
- 25 Information and Communications Technology Professionals
- 31 Science and Engineering Associate Professionals
- 35 Information and Communications Technicians

The table below lists all occupations, at a four-digit ISCO-08 level, included in the present study. As most databases disaggregate at the two-digit level, it is not always possible to apply narrower definitions of STEM – as an example, the presence of architects (ISCO-08-216) could be up for debate – and therefore some non-STEM occupations may be included in the analysis.

*Table 6 STEM occupations, three- and four-digit ISCO-08 classifications*

| ISCO name (3-digit) | Code | ISCO name (4-digit) |
|---|---|---|
| | | **21 Science and Engineering Professionals** |
| **211 Physical and Earth Science Professionals** | **2111** | Physicists and Astronomers |
| | **2112** | Meteorologists |
| | **2113** | Chemists |
| | **2114** | Geologists and Geophysicists |
| **212 Mathematicians, Actuaries and Statisticians** | **2120** | Mathematicians, Actuaries and Statisticians |
| **213 Life Science Professionals** | **2131** | Biologists, Botanists, Zoologists and Related Professionals |
| | **2132** | Farming, Forestry and Fisheries Advisers |
| | **2133** | Environmental Protection Professionals |
| **214 Engineering Professionals** | **2141** | Industrial and Production Engineers |
| | **2142** | Civil Engineers |
| | **2143** | Environmental Engineers |

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| | | |
|---|---|---|
| **(excluding Electrotechnology)** | **2144** | Mechanical Engineers |
| | **2145** | Chemical Engineers |
| | **2146** | Mining Engineers, Metallurgists and Related Professionals |
| | **2149** | Engineering Professionals Not Elsewhere Classified |
| **215 Electrotechnology Engineers** | **2151** | Electrical Engineers |
| | **2152** | Electronics Engineers |
| | **2153** | Telecommunications Engineers |
| **216 Architects, Planners, Surveyors and Designers** | **2161** | Building Architects |
| | **2162** | Landscape Architects |
| | **2163** | Product and Garment Designers |
| | **2164** | Town and Traffic Planners |
| | **2165** | Cartographers and Surveyors |
| | **2166** | Graphic and Multimedia Designers |
| **25 Information and Communications Technology Professionals** | | |
| **251 Software and Applications Developers and Analysts** | **2511** | Systems Analysts |
| | **2512** | Software Developers |
| | **2513** | Web and Multimedia Developers |
| | **2514** | Applications Programmers |
| | **2519** | Software and Applications Developers and Analysts Not Elsewhere Classified |
| **252 Database and Network Professionals** | **2521** | Database Designers and Administrators |
| | **2522** | Systems Administrators |
| | **2523** | Computer Network Professionals |
| | **2529** | Database and Network Professionals Not Elsewhere Classified |
| **31 Science and Engineering Associate Professionals** | | |
| **311 Physical and Engineering Science Technicians** | **3111** | Chemical and Physical Science Technicians |
| | **3112** | Civil Engineering Technicians |
| | **3113** | Electrical Engineering Technicians |
| | **3114** | Electronics Engineering Technicians |
| | **3115** | Mechanical Engineering Technicians |
| | **3116** | Chemical Engineering Technicians |
| | **3117** | Mining and Metallurgical Technicians |
| | **3118** | Draughtspersons |
| | **3119** | Physical and Engineering Science Technicians Not Elsewhere Classified |
| **312 Mining, Manufacturing and Construction Supervisors** | **3121** | Mining Supervisors |
| | **3122** | Manufacturing Supervisors |
| | **3123** | Construction Supervisors |
| **313 Process Control Technicians** | **3131** | Power Production Plant Operators |
| | **3132** | Incinerator and Water Treatment Plant Operators |
| | **3133** | Chemical Processing Plant Controllers |
| | **3134** | Petroleum and Natural Gas Refining Plant Operators |
| | **3135** | Metal Production Process Controllers |
| | **3139** | Process Control Technicians Not Elsewhere Classified |
| **314 Life Science Technicians and Related Associate Professionals** | **3141** | Life Science Technicians (excluding Medical) |
| | **3142** | Agricultural Technicians |
| | **3143** | Forestry Technicians |
| **315 Ship and Aircraft Controllers and Technicians** | **3151** | Ships' Engineers |
| | **3152** | Ships' Deck Officers and Pilots |
| | **3153** | Aircraft Pilots and Related Associate Professionals |
| | **3154** | Air Traffic Controllers |
| | **3155** | Air Traffic Safety Electronics Technicians |
| **35 Information and Communications Technicians** | | |
| **351 ICT Operations and User Support Technicians** | **3511** | Information and Communications Technology Operations Technicians |
| | **3512** | Information and Communications Technology User Support Technicians |
| | **3513** | Computer Network and Systems Technicians |

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| | | |
|---|---|---|
| | **3514** | Web Technicians |
| **352 Telecommunications and Broadcasting Technicians** | **3521** | Broadcasting and Audiovisual Technicians |
| | **3522** | Telecommunications Engineering Technicians |

### 2.3.3 Curricula analysis

Our curricula analysis targeted the following research sub-question:

- *RQ3: To what extent do innovative practices prepare students with STEM skills? What are the main initiatives to foster STEM skills in the EU?*

As part of T2.3, we performed an analysis of curricula and course requirements from the world's leading STEM departments. To do so, the latest QS World University Ranking[9] has been used as a benchmark. QS ranks universities by academic discipline organized into 5 faculties and 42 subjects. Faculties include Engineering & Technology, Life Sciences & Medicine, Natural Sciences, Arts & Humanities, and Social Sciences & Management. We identified the first three faculties as STEM-related. Taken together, they contain 21 subjects, of which 12 correspond to STEM subjects as defined by the ISCED codes chosen above. The following table shows a correspondence between the two categorizations.

*Table 7 QS – ISCED correspondence table*

| Faculty (QS) | Subject (QS) | Code (ISCED) | Current study |
|---|---|---|---|
| **Engineering & Technology** | Chemical engineering | 52 | |
| | Civil & structural engineering | 58 | |
| | Computer Science & Information Systems | 48 | |
| | Electrical & electronic engineering | 52 | |
| | Mechanical, aeronautical & manufacturing engineering | 52 | |
| | Mineral & Mining Engineering | 54 | |
| **Life Sciences & Medicine** | Agriculture & Forestry | 62 | |
| | Biological Sciences | 42 | |
| | Dentistry | 72 | |
| | Medicine | 72 | |
| | Nursing | 72 | |

[9] QS World University Rankings by Subject 2016 _ Top Universities. Available at http://www.topuniversities.com/subject-rankings/2016 (retrieved 15 December 2016).

| | | | |
|---|---|---|---|
| | Pharmacy & Pharmacology | 72 | |
| | Psychology | 31 | |
| | Veterinary Science | 64 | |
| Natural Sciences | Chemistry | 44 | |
| | Earth & Marine Sciences | 44 | |
| | Environmental Sciences | 42 | |
| | Geography | 31 | |
| | Materials Sciences | 54 | |
| | Mathematics | 46 | |
| | Physics & Astronomy | 44 | |

For each the 12 resulting subjects, we have analysed and explored degree requirements, curricula, and study plans of undergraduate STEM courses at the five highest ranking universities, with a focus on the recurring ones:

- Massachusetts Institute of Technology (MIT) (12 times in the top-5)
- Stanford University (11)
- University of Cambridge (9)
- University of California, Berkeley (UCB) (8)
- University of Oxford (5)
- Imperial College London (2)

Our objective was to keep a global perspective in order to spot elements of excellence, or degree features that could be exemplar for all European universities to be prepared to meet future STEM skill requirements. The following table lists the world's top five universities by STEM subject.

*Table 8 Top 5 Universities by STEM field, global*

| STEM subject (QS) | Rank | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| **Biological Sciences** | Harvard University | University of Cambridge | Massachusetts Institute of Technology (MIT) | University of Oxford | Stanford University |
| **Chemical engineering** | Massachusetts Institute of Technology (MIT) | Stanford University | University of California, Berkeley (UCB) | University of Cambridge | National University of Singapore (NUS) |
| **Chemistry** | Massachusetts Institute of Technology (MIT) | University of California, Berkeley (UCB) | University of Cambridge | Harvard University | Stanford University |

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| | | | | | |
|---|---|---|---|---|---|
| **Computer Science & Information Systems** | Massachusetts Institute of Technology (MIT) | Stanford University | University of Oxford | Harvard University | Carnegie Mellon University |
| **Earth & Marine Sciences** | ETH Zurich - Swiss Federal Institute of Technology | Harvard University | University of California, Berkeley (UCB) | Massachusetts Institute of Technology (MIT) | University of Oxford |
| **Electrical & electronic engineering** | Massachusetts Institute of Technology (MIT) | Stanford University | University of Cambridge | University of California, Berkeley (UCB) | University of California, Los Angeles (UCLA) |
| **Environmental Sciences** | University of California, Berkeley (UCB) | Stanford University | Massachusetts Institute of Technology (MIT) | Wageningen University | Harvard University |
| **Materials Sciences** | Massachusetts Institute of Technology (MIT) | Stanford University | Imperial College London | University of California, Berkeley (UCB) | University of Cambridge |
| **Mathematics** | University of Cambridge | Harvard University | Massachusetts Institute of Technology (MIT) | Stanford University | University of Oxford |
| **Mechanical, aeronautical & manufacturing engineering** | Massachusetts Institute of Technology (MIT) | Stanford University | University of Cambridge | University of California, Berkeley (UCB) | Imperial College London |
| **Mineral & Mining Engineering** | Colorado School of Mines | Massachusetts Institute of Technology (MIT) | Stanford University | University of Cambridge | University of Oxford |
| **Physics & Astronomy** | Massachusetts Institute of Technology (MIT) | Harvard University | Stanford University | University of Cambridge | University of California, Berkeley (UCB) |

Due to the diversity in the composition of curricula and the requirements across countries and outside the EU-28, as well as the difference in educational systems, findings from the analysis are descriptive and limited. However, following a complementarity and triangulation approach, we then integrated the findings with a scoping review of key innovative practices and initiatives in STEM in Europe, both within and outside universities. Findings from the curricula analysis are specifically set to influence and contribute to the work of WP3 and WP5.

### 2.3.4 In-depth interviews

Our interviews aimed at answering the following research sub-questions:

- *RQ1: What is the extent and nature of the EU labour market for STEM skills?*

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- *RQ4: How is the EU market demand for STEM skills likely to evolve in the future, and which STEM skills will likely be most in demand?*

**In-depth interviewing** is a powerful research technique. It consists of conducting intensive individual interviews with a small number of participants to explore their take on a given topic. They are used to provide context, and corroborate the evidence gathered from other sources, offering a more complete picture. Their main advantage is that they provide much more detailed insights than what would be available through surveys or other data collection methods. They also provide a more comfortable environment in which to collect data, as opposed to filling out surveys.

Our process consisted in the following steps: planning, developing instruments, collecting data, and analysing. While planning, we have identified our target group in **employers from small and large STEM-intensive enterprises**. More specifically, we specified respondents to be senior executives:

- In small and medium-sized companies, this tended to be the managing director, CEO or chairman;
- in larger firms, it was the HR director or equivalent.

A purposive sampling inspired by the principle of representation guided the selection of companies: firms had to be representative of different typological and characterising elements (class size, industry sectors, geography). We conducted a total of **11 in-depth individual interviews**. Our goal, as pointed before, was to better understand the current and future demand for STEM skills. Therefore, we selected only sectors where the demand for STEM skills is strong and likely to be affected by change, as we were informed by the literature review. The following sectors were identified:

- Automotive
- Biotechnology
- Business Services
- Computer Programming, Data Processing (2)
- Cosmetics
- Electrical/Electronic Manufacturing (2)
- Food Manufacturing
- Research and Development (R&D)

In terms of size, respondents worked in firms of different categories:

- Micro (3)
- Small (4)
- Medium (2)
- Large (2)

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Finally, we selected countries according to the findings of our data analysis, trying to capture different contexts with different STEM skills supply and demand. Our final selection included the following EU Member States:

- Poland (1), where the share of STEM graduates is low, and the number of STEM jobs is one of the lowest, especially among ICT associate professionals;
- Spain (4), a country with a decreasing share of STEM graduates, and with high and increasing employment in ICT;
- Greece (2), where the share of STEM students is the second highest in the EU-28, and which ranks at the bottom quartile in STEM employment;
- Slovenia (4), a country with the highest growth in STEM graduates, and a high and rising number of STEM professionals working in science and engineering (S&E).

Once we defined the target group and planned, we elaborated **detailed interview guidelines**. These were rules that guided the administration and execution of the interviews, to ensure consistency between interviews, and increase reliability of findings. However, they only served as prime guidance for the interviewers. The interview was semi-structured, therefore it allowed for additional information to be taken on board, depending on how it evolved. **Guidelines** meant to address the interview were arranged around the following topics:

- STEM skills
- Recruitment Practices
- Apprenticeships
- Links with schools and universities
- Future STEM demand

The following table displays the questions centered around each of the topics mentioned above.

*Table 9: STEM Interview guidelines*

| Theme | Question |
| --- | --- |
| ***I: ABOUT YOUR COMPANY*** | • *Do you currently employ people with STEM-related degrees and qualifications in your company? What are their main roles (e.g. managers, technicians, professionals)?* |
| ***II: SKILLS*** | • *The demand for people with STEM qualifications is closely linked to the skills that they bring to the workplace. Employers typically welcome capabilities in active learning, critical thinking, complex and creative problem-solving, all of which correlate closely with STEM qualification based skills. To what extent are these skills important to your company?*<br>• *What other skills and attributes are important to your company?* |

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| | |
|---|---|
| | • *As a whole, do you consider the skills of your workforce adequate? Do your employees lack certain skills (e.g. IT literacy, numeracy, foreign language skills)? Do you provide remedial training?* |
| ***III: RECRUITMENT*** | • *What do you look for when you are hiring new staff (e.g. attitudes, past experience, degree subject, university name, foreign language skills…)? Do you actively seek for people with STEM degrees? Which STEM subjects do you find more important for your company? Is there any particular degree that suits your company better?*<br>• *Have you encountered difficulties in recruiting STEM-skilled? If so, which problems do you encounter? (E.g. shortage of supply, lack of workplace experience, non-relevant degree, wrong attitude, lack of interpersonal skills…)* |
| ***IV: APPRENTICESHIPS*** | • *Is your company involved in apprenticeships programs? How does it work? What kind of training do you provide? (e.g. basic, advanced…)*<br>• *(If yes) Despite the current economic pressures, do you plan to maintain or increase investments in training over the coming year? What do you think are the main barriers to overcome in order to promote the success of these programs (e.g. more guidance on how to make work experience worthwhile, less onerous requirements, reduce bureaucracy around government financing, etc.)?* |
| ***V: SCHOOLS AND UNIVERSITIES*** | ***Higher education institutions***<br>• *Strengthening links between universities and business has the potential to enhance economic growth. Businesses look to higher education to develop people with the right knowledge and skills to meet their future needs. Has your company developed links of some type with universities (e.g. for internships, graduate programs, R&D partnerships)? Are you looking to grow these ties with universities in the future? Do you provide some kind of specific projects or resources to help students understand the practical relevance of their courses?*<br>***Schools***<br>• *What happens in schools is equally important for the future of our economy and society. Has your company built links with secondary schools or further education colleges in the past 3 years? What kind of programs or collaborations do you share (e.g. career advice, work experience for pupils, curriculum development)?* |
| ***VI: FUTURE DEMAND*** | • *Over the next 3 to 5 years, do you expect to hire more (or less) staff with higher-level skills?*<br>• *As reported by the literature, while employers are confident there will be enough people available to fill their low-skilled vacancies, the same is not true for the demand of high-skilled employees. How confident are you in being able to recruit high-skilled employees in the future?*<br>• *Government can help tackle future STEM skills supply shortages, for example by promoting science and maths in schools. Which actions do you think the government should take to encourage the study of STEM disciplines? (e.g. more apprenticeships, financial incentives, closer ties with business…)* |

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| | |
|---|---|
| | • *Is there anything else we should discuss regarding the topics we have addressed at this point?* |
| ***Concluding question*** | • *Of all the things we have discussed today, what would you say are the most important issues you would like to express about the future demand for STEM skills?* |

Once interviews were set up, we explained the purpose, the duration, and the selection criteria to the respondents. We then conducted the interview, after which we summarized the key data, fact-checked information where necessary, and conducted a **thematic content analysis.** This type of analysis, very common in qualitative research, emphasizes analysing patterns – or themes – within data. It provides a flexible method and allows for researchers with various methodological backgrounds to engage in it. It encompassed the following steps: first, getting familiar with the interview transcripts, by reading and re-reading them; second, by labelling the whole text; third, by searching for patterns, or themes, with broader meaning; fourth, by reviewing such themes to ensure they fit the information; fifth, by naming themes; sixth, by writing a consistent, organized narrative that included quotes from the interviewees. The nature of in-depth interviews and the small sample do not allow for generalised conclusions or external validity. Nonetheless, this method was consistently applied, and themes spurring from the analysis were reported on in a likewise fashion, forming the respective sections of D2.1 and D2.2 related to the specific sub-questions.

#### 2.3.5 Validation Workshop

Our validation workshop targeted the following research sub-questions:

- *RQ3: To what extent do innovative practices prepare students with STEM skills? What are the main initiatives to foster STEM skills in the EU?*
- *RQ4: How is the EU market demand for STEM skills likely to evolve in the future, and which STEM skills will likely be most in demand?*

As envisaged in the project proposal, a workshop was performed in the context of T2.2 "Development and validation of the scenarios and trends". The discussion focused on scenarios for the STEM labour market built with the input from T2.1 "Analysis of Supply and Demand Side of STEM". The workshop had the aim to validate and expand the information presented in D2.1, and to provide relevant input for the present deliverable as well as to the other project WPs.

The workshop took place on 1 December at the JSI premises (Ljubljana, Slovenia), during the STEM plenary meeting. The participants included members of the Consortium as well as external stakeholders from NGOs, private companies, and higher education. Overall, there were 23 representatives of universities, research institutes, NGOs and the private

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sector. This diverse audience provided different points of views which enriched the discussion. First, the main conclusions from the analysis of the STEM supply and demand (T2.1) were exposed in order to contextualise the discussion and to provide information on the current situation of the STEM labour market as well as on some estimations. This was followed by the presentation of the scenarios.

**Scenario building** helps to predict and shape the innovation process by stimulating different perspectives or images on the future of a certain area in order to allow better predictions for evolution. To develop the scenarios, we used **trend analysis** techniques, according to which the scenarios reflect the type of future to which the trends may lead. Instrumental for the scenario definition we used both **state of play**, establishing the baseline of the foresight, and **gap analysis**, comparing the scenarios against the state of play to identify what is lacking for making desirable elements of the scenarios happen and for avoiding undesirable ones. The process of scenario building was based on the following steps:

- identification of the main trends,
- classification of trends,
- organization of trends,
- deriving concerted scenarios,
- communication of the scenarios.

In the present case, the scenarios were assumed to take place in ten years' time and depended on **the evolution of two key variables: supply and demand of the STEM labour market.** In the period spanning from 2016 to 2025, both variables might fluctuate several times, but, in sum, they can increase, decrease or remain the same. The combination of these possibilities generates nine different scenarios, which are represented in the figure below. For instance, the scenario in the top-left corner represents the situation in which both demand and supply increase. On the other hand, in the bottom-centre scenario, supply decreases while demand stays the same.

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*Figure 1 Evolution of STEM labour market supply and demand, 2016-2025*

Demand (+/-); Supply (-/+)

| | | |
|---|---|---|
| S⇧ D⇧ | S⇧ D= | S⇧ D⇩ |
| S= D⇧ | S= D= | S= D⇩ |
| S⇩ D⇧ | S⇩ D= | S⇩ D⇩ |

It is important to note that the current scenario is assumed to be an equilibrium between supply and demand. Therefore, in the latter case there would be a shortage of supply respect to demand, this is, the number of employees with STEM skills would not be enough to cover the demand from the employers. This situation would also occur if demand increases while supply remains unchanged, and if demand rises and supply falls.

*Figure 2 Shortage of supply scenarios*

Demand (+/-); Supply (-/+)

| | | |
|---|---|---|
| S⇧ D⇧ | S⇧ D= | S⇧ D⇩ |
| S= D⇧ | S= D= | S= D⇩ |
| S⇩ D⇧ | S⇩ D= | S⇩ D⇩ |

The following figure shows the opposite situation, when there is a surplus of supply respect to demand. Here, there are more people with STEM skills that are willing to work than job vacancies suited to them.

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*Figure 3 Surplus of supply scenarios*

Demand (+/-)

| Supply (-/+) | | | |
|---|---|---|---|
| | S D | S D= | S D |
| | S= D | S= D= | S= D |
| | S D | S D= | S D |

Finally, the other three scenarios imply a maintenance of the current equilibrium, provided that demand and supply rise at the same rate (top-left) or decline by the same amount (bottom-right).

*Figure 4 Equilibrium between supply and demand scenarios*

Demand (+/-)

| Supply (-/+) | | | |
|---|---|---|---|
| | S D | S D= | S D |
| | S= D | S= D= | S= D |
| | S D | S D= | S D |

All these scenarios are possible. However, as is seen in D2.1, the market analysis provides some insight about which of them is more feasible. According to CEDEFOP data, employment in STEM would grow by 8.2 million jobs in ten years (2016-2025). Therefore, demand will be assumed to grow and, thus, scenarios are reduced to three. In all of them demand rises, but the behaviour of supply varies. In the first scenario, STEM supply either falls, stays the same, or increases but less than demand. As a consequence, there is a **shortage** of STEM supply, meaning that there are more STEM jobs than graduates. In the second scenario, supply keeps pace with demand and, thus, the **equilibrium** is maintained. In this, the number of STEM jobs matches that of STEM graduates. In the last

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scenario, the growth of STEM supply surpasses that of demand, creating a situation of **surplus** of STEM supply, in which there are more STEM graduates than jobs.

The interactive workshop hosted relevant stakeholders who discussed the scenarios developed. Small group discussions were held to be effective in ensuring in-depth analysis and high value contributions, such as well develop recommendations and inspiring cases. The stakeholders were engaged in interactive activities to achieve a consensus among participants in the prioritization of the scenarios and thus to identify the most promising ones according to the project requirements.

Participants were divided in smaller groups in order to discuss in deep each of the three scenarios, to allow for a dynamic discussion, and to ensure that everybody could contribute. A group was created for each of the three scenarios. Groups were requested to **identify the challenges** that the scenario posed **to universities, the private sector, and the government**, stylizing a high-level SWOT. **SWOT analysis** is a diagnostic tool that analyses the strengths and weaknesses of a given option and assesses the future opportunities and threats to it. This type of analysis is most likely to draw on documentary (e.g. previous studies, etc.), statistical sources of data and interviews with key informants. This technique can be used, applying the principle of inter-subjective objectivity, to fill in qualitatively but treat quantitatively cost-benefit or cost-effectiveness templates. According to the principle of inter-subjective objectivity, if a large enough number of individuals with some relevant expertise are asked to provide their subjective judgment (but using evidence provided by the evaluators) on an evaluation question, by averaging their aggregate answer, one moves away from subjectivity and somehow approaches objectivity, especially if the respondents have the right expertise/experience. In this case, the SWOT analysis was instrumental to the scenario validation and therefore focused on the Opportunities and Threats.

The **Delphi survey** is a structured group interaction process involving a sample of experts in which participants, unlike expert panels, are kept separate in order to avoid bias. Delphi survey is used to obtain independent expert-based and non-biased opinions on a technical or very specific issue. In a similar fashion, participants were individually asked to **suggest recommendations** for the respective stakeholders to help them face the challenges. In this case, time and space constraints suggested to move away from anonymity and towards a face-to-face interaction. Furthermore, experience shows that participants welcome an extra round to discuss results in a general meeting. Therefore, participants had about twenty minutes to debate. Later, the key findings were collected and presented in front of the whole audience.

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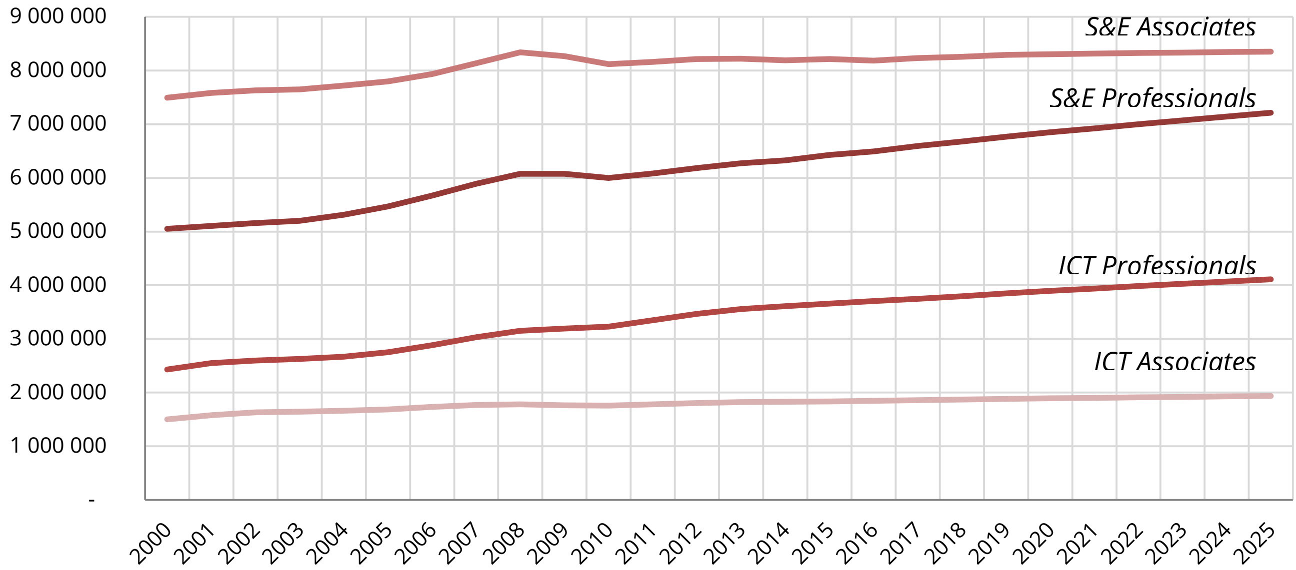
# 3 Evolution of the labour market for STEM skills

## 3.1 STEM demand forecast

**In the period 2015-2025, there will be 8.2 million new STEM jobs in the EU**. The figure, based on CEDEFOP data, amounts to the number of people who will be required to work in one of the four STEM occupations, given projected changes in employment and replacement demands. Each of the four STEM occupations is expected to have a positive employment balance.

*Figure 5 Future STEM employment, absolute numbers*




*Source: Authors' elaboration on CEDEFOP data*

According to CEDEFOP, by 2025 employment for S&E and ICT professionals is projected to increase by 12.5% and 11.8% respectively, which means around 2.9 and 1.9 million job openings including replacement demands. To a lesser extent, projected change in employment to 2025 for S&E and ICT associate professionals amounts to 1.9% and 5.2% respectively, which translates to around 2.7 and around 0.7 million job openings including replacement demands.

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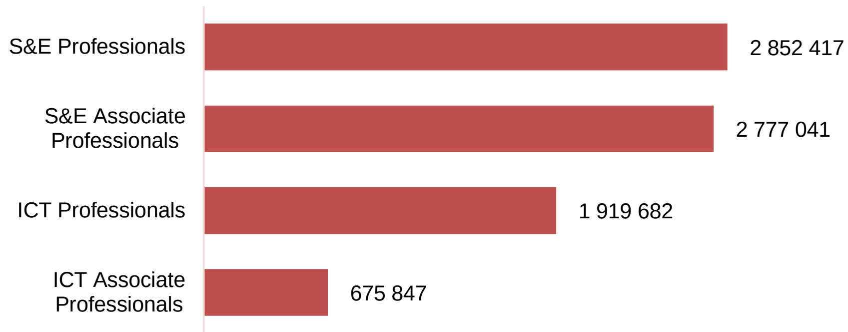
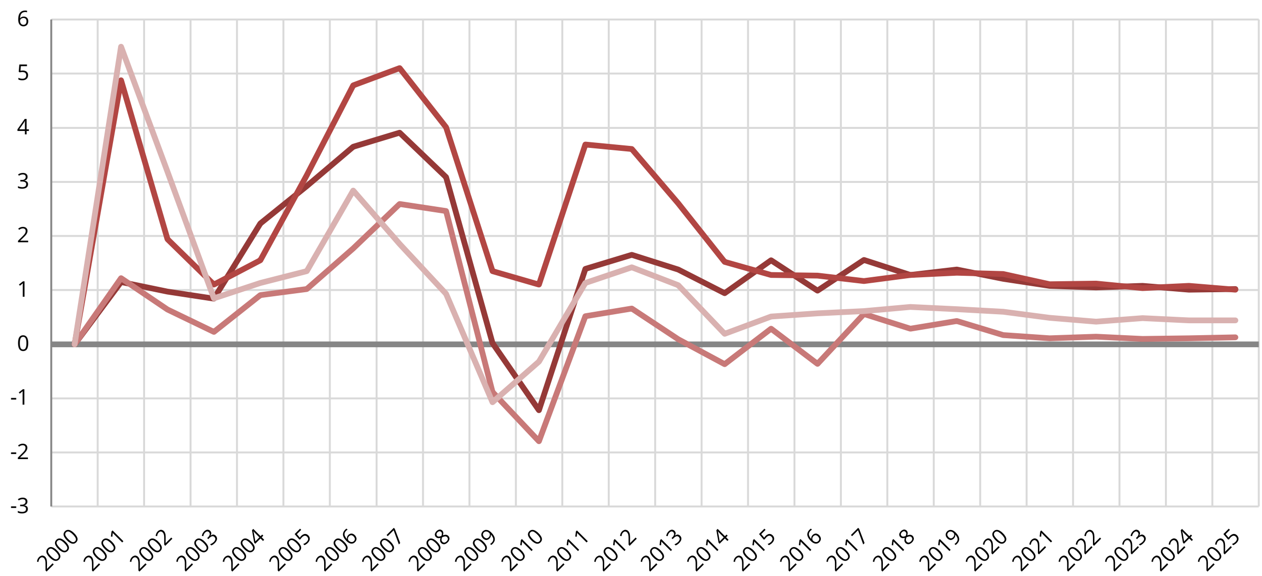
Figure 6 STEM job openings in the EU, 2015-2025




*Source: Authors' elaboration on CEDEFOP data*

After more than a decade of high fluctuations, between 2015 and 2025 the growth of STEM occupations will converge to steady states according to CEDEFOP projections. In particular, the annual growth rate of professionals (S&E and ICT alike) by 2025 is expected to be at around +1.0%, while associate professionals are expected to experience a smaller, yet positive, growth.

Figure 7 Future STEM employment, annual growth rate (%)




*Source: Authors' elaboration on CEDEFOP data*

When looking at the country breakdown, as the following figure shows, two patterns seem to stand out. On the one hand, with regards to STEM professionals, nearly all Member States will enjoy employment growth to at least a certain extent. On the other hand, with regards to STEM associate professionals, employment will decrease in nearly half Member States. Associa te professionals might be at risk of replacement due to technological advancement in automation (Chui et al., 2016).More specifically,

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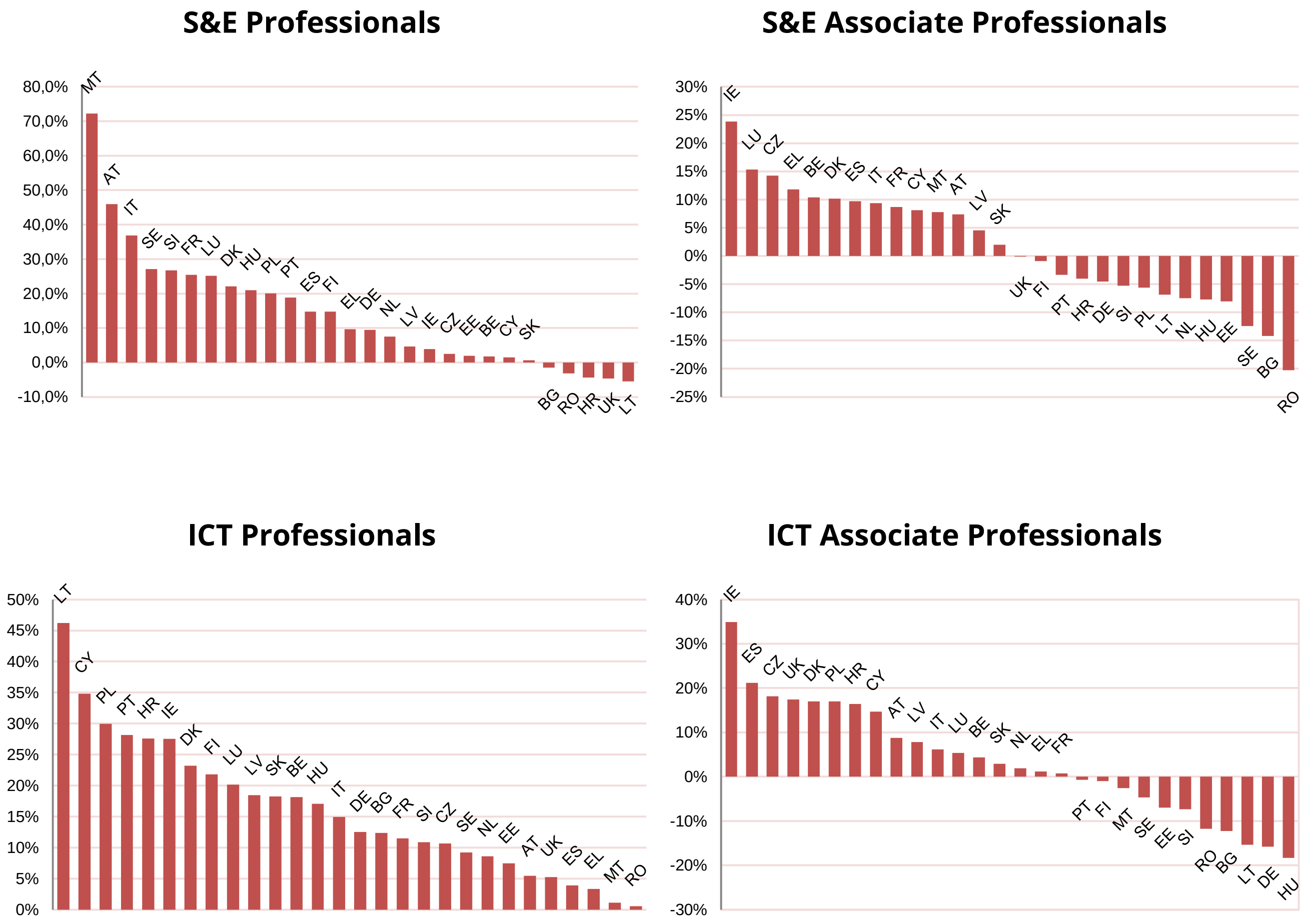
employment of S&E professionals is especially likely to increase in Malta (+72.3%), Austria (+45.9%) and Italy (+36.9%), while it is expected to slightly drop in Lithuania (-5.5%), the United Kingdom (-4.7%), and Croatia (-4.4%). Conversely, employment of ICT professionals in Lithuania is particularly expected to increase (+46.2%), and so it will everywhere else across the EU, including Cyprus (+34.8%) and Poland (+30.0%). Romania (+0.6%) and Malta (+1.1%) show a more modest forecast. With regards to Employment of S&E associate professionals, it will especially increase in Ireland (+23.8%), Luxembourg (+15.4%) and Czech Republic (+14.3%), whereas it is expected to drop significantly in Romania (-20.3%), Bulgaria (-14.2%) and Sweden (-12.4%). Similarly, employment of ICT associate professionals is expected to rise in Ireland (+34.9%) and Czech Republic (+18.2%), as well as in Spain (+21.2%), and is expected to drop in Hungary (-18.3%), Germany (-15.8%) and Lithuania (-15.4%).

*Figure 8 Future STEM employment growth (in %) across the EU in 2015-2025*




*Source: Authors' elaboration on CEDEFOP data*

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**Future growth in STEM employment is likely to be unevenly distributed across EU Member States.** This is further explained in the following heatmap, in which the percentage change for each STEM occupation is broken down by Member State. In Austria, Sweden, Slovenia, and Malta, for example, employment growth will mostly be a matter of S&E professionals. In Finland, France, Germany, Hungary, Italy, Luxembourg, Portugal, employment of professionals (either ICT or S&E) is likely to increase. At the same time, Germany and Hungary are expected to have a drop in employment of associate professionals, and so are Bulgaria, Lithuania and Romania. Employment will increase to at least a certain extent across all STEM occupations in Denmark, Spain, Czech Republic, Ireland and Luxembourg.

*Table 10 Future STEM employment growth (in %) across the EU in 2015-2025*

| | S&E Professionals | S&E associate professionals | ICT professionals | ICT associate professionals |
|---|---|---|---|---|
| Austria | 46% | 7% | 5% | 9% |
| Belgium | 2% | 10% | 18% | 4% |
| Bulgaria | -2% | -14% | 12% | -12% |
| Croatia | -4% | -4% | 28% | 16% |
| Cyprus | 1% | 8% | 35% | 15% |
| Czech Republic | 2% | 14% | 11% | 18% |
| Denmark | 22% | 10% | 23% | 17% |
| Estonia | 2% | -8% | 7% | -7% |
| Finland | 15% | -1% | 22% | -1% |
| France | 25% | 9% | 11% | 1% |
| Germany | 9% | -5% | 13% | -16% |
| Greece | 10% | 12% | 3% | 1% |
| Hungary | 21% | -8% | 17% | -18% |
| Ireland | 4% | 24% | 28% | 35% |
| Italy | 37% | 9% | 15% | 6% |
| Latvia | 5% | 5% | 18% | 8% |
| Lithuania | -6% | -7% | 46% | -15% |
| Luxembourg | 25% | 15% | 20% | 5% |
| Malta | 72% | 8% | 1% | -3% |
| Netherlands | 8% | -7% | 9% | 2% |
| Poland | 20% | -6% | 30% | 17% |
| Portugal | 19% | -3% | 28% | -1% |
| Romania | -3% | -20% | 1% | -12% |
| Slovakia | 1% | 2% | 18% | 3% |
| Slovenia | 27% | -5% | 11% | -7% |
| Spain | 15% | 10% | 4% | 21% |
| Sweden | 27% | -12% | 9% | -5% |
| United Kingdom | -5% | 0% | 5% | 17% |

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*Source: Authors' elaboration on CEDEFOP data*

## 3.2 STEM skills analysis

According to CEDEFOP, many of the STEM job openings in 2025 will be a consequence of replacement demand. However, the rising demand will likely be driven by a number of industry-specific vertical trends, as well by cross-sector horizontal trends, which will accordingly shape the needs for new, diversified skill sets across STEM fields.

### 3.2.1 Vertical trends

The **skills profiles** of STEM workers depend and adapt to the developments and trends of the industries they work for**.** In the energy sector, the transition from traditional to renewable sources has changed the industry framework and the profile of skills required. Traditionally concentrated, capital-intensive, and often government-led, large energy companies had been relatively stable employers with fair levels of pay. The growth of renewable energy has significantly fragmented industry: a larger proportion of employment is in new companies, and more work is **project-based**. Fast deployment could lead to shortages in technical occupations such as **solar installers** and **electrical engineers** (EC Joint, 2011).

The concern for climate change is also likely to increase employment opportunities. Governments committed to the 2016 Paris Agreement on carbon emissions will increase public sector funding, which in turn is likely to create jobs in **deploying, operating and maintaining renewable energy projects** (Walt, 2015; IEA, 2016). In addition, climate change **impact prevention and mitigation activities** grow in many more sectors than before. Demand for **specialist operations** and **development expertise** in photovoltaic technology, wind power and energy savings could increase. Engineers and life scientists equipped with **data analytics, systems, risk management, project management** skills would then be needed to support R&D in these fields (Brennan & Limmer, 2015).

The emergence of the marine renewable energy (MRE) industry is also creating new skillsets from the combination of many different areas. New STEM occupational profiles, such as the **wind turbine service technician**, are likely to be formed (Podevin, 2015). In the oil & gas market, the reducing demand for fossil fuels in Europe, together with falling oil prices and the outsourcing of complex refinery infrastructure outside of the EU, might reduce demand for STEM professionals (Lukoil 2013; Fitzgibbon et al., 2015).

In the construction sector, rising technologies such as the Building Information Modeling (BIM) integrate planning and landscaping with data analytics, smart homes and the Internet of Things (IoT) while minimising environmental impact. The EU is already investing on sustainable urban development (European Commission, 2013). In the UK, the government has recently made BIM compulsory on all public works. Professionals in the sector will need to adapt and possess **expertise on data management** and other new skills (UK Government, 2015). Other innovations in the constructing industry, such as geo-location and **higher-definition surveying**, will likely impact the skills profile for S&E associate professionals such as **geology technicians** (Agarwal et al., 2016). Employment of STEM technicians in the construction sector is also likely to benefit from the growing demand for environmentally sensitive and energy efficient buildings (Pye and Dobbins, 2015).

In the automotive industry, electronics contribute 30% of car production costs. This is expected to reach 50% by 2030[10]. Electronic systems already account for 90% of car innovations and new features (Coulon, 2014). As a consequence, **skills for manufacturing and developing electronic parts** are expected to increase, at the cost of traditional mechanical engineering skills. The biotechnology industry, one of the Key Enabling Technologies (KET) under Horizon 2020, is expected to grow from EUR 28 billion to EUR 50 billion by 2030 (BIO-TIC, 2015). With biotech driving innovation in many sectors - chemicals, food, detergents, paper, textiles, bioenergy, agriculture, healthcare - demand for **biotech skills** is likely to rise exponentially (EY, 2014).

### 3.2.2 Horizontal trends

In addition to industry-specific trends, a number of cross-sectoral factors could further shape the demand for STEM workers. One example is the growing importance of **automation**. As industry invests in advanced robots, smart homes, virtual personal assistants, and driverless cars, the demand for **software and hardware experts** by start-ups - as well as by established organizations - is likely to rise (West, 2015). Whereas disruptions such as 3D printing and robotics are expected to cause an overall decline in the demand for jobs, the opposite is true with regards to STEM professionals and technicians, due to the need for **high-skilled specialists** able to develop and execute advanced production systems (WEF, 2016).

The Big Data trend is creating demand for jobs with data analytical skills, **data management** and **data scaling skills** (Morrison, 2016). New jobs, such as data scientist and Chief Analytics Officer (CAO), have already surfaced (Foo, 2013). Likewise, as more and more enterprises and consumers shift to cloud computing, technical knowledge shifts away from users towards cloud providers (IDC, 2014). Companies in the sector will need STEM professionals and technicians equipped with skills including **cloud design**

[10] Automotive electronics costs wordwide 2030Forecast.Available at https://www.statista.com/statistics/277931/automotive-electronics-cost-as-a-share-of-total-car-cost-worldwide (retrieved 31 October 2016).

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**and management, service integration and management**, and **cloud data centre building and optimization** (Darrow, 2015).

The growing **Internet of Things** (IoT) is also likely to boost the demand for those STEM professionals and technicians with the capacity to handle diversified systems, and for those with an **understanding of architecture, design, standardisation and interoperability**. **Network management skills** are also expected to increase, as well as technical knowledge of IoT. (WEF, 2016). Changes in consumer demand towards more customized products and services have resulted in new, technology-intensive and flexible production processes, known as "Industry 4.0" (Bundesministerium für Bildung und Forschung, 2014). Industry 4.0 creates "Smart factories", where cyber-physical systems interact with IoT and the Internet of Services[11]. STEM specialists will need to possess additional software and hardware **skills to develop complex human-independent machines** able to interact with each other (Schlepper and Koch, 2015).

With the growth in smart devices, and a constant demand for **interoperability, standardization** activities are likely to increase (European Commission, 2011). Standardizations are already under way in 5G networks, 3D printing, and IoT (IERC, 2015). The effect of a growth in standards and patents on employment is ambiguous: on one hand, it could lead to a larger demand for STEM professionals who work on product specifications; on the other hand, existing STEM professionals might lose their jobs as the standards they are specialized in become obsolete. Smart systems also open a new window of attack for **cybercrime** and cyberterrorism (Nugent, 2016). Security defences of the interconnected, "smart" infrastructures of the future will have to expand beyond the conventional borders of existing computing systems. As a consequence, the demand for **cybersecurity skills** is likely to increase, together with **business skills to manage trust and risk** (Cisco, 2015).

Lastly, the international fragmentation of production is on the rise, with intermediates now accounting for 50% of world trade in manufacturing (OECD, 2015). Globalization has transformed innovation into an **international, collaborative activity** (WEF, 2015). The number of jobs involved in global value chains (GVCs) has increased in Europe, as did the share of high skilled workers, including STEM professionals. Meeting foreign demand will require relatively high shares of highly-skilled workers (OECD, 2015). In addition, strong **communication skills** will be increasingly important to lead and work in such international and collaborative environments (McDougall, 2014).

[11] Internet of Services - SAP Research - SCN Wiki. Available at https://wiki.scn.sap.com/wiki/display/Research/Internet+of+Services (retrieved 31 October 2016).

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### 3.2.3 Insights from in-depth interviews

**Among interviewed employers, many are confident that they will be constantly hiring STEM skilled professionals in the next 5 years.** According to an employer from a medium-sized Spanish company, after the strong impact the Spanish market suffered during the economic crisis a recovery and the market awakening are on sight. As reported by this employer, his company is growing and they will hire more people. He was positive of being able to find and recruit high-skilled employees. There are many professionals currently working in Germany, France, the UK, who left during the economic recession and are moving back to Spain now that they are able to find good job opportunities there too. This would be good news for the Spanish industry as these professionals have been trained in more advanced markets and they return with additional experience. The same employer believes that the offer of STEM graduates will be enough to cover the needs of the industry, and that perhaps there will be a shortage in some specific disciplines such as informatics engineering, which are in strong demand at the moment. He added that this might be different in other European countries, where a shortage of supply might occur for different reasons - not enough people considering STEM programs in universities, for example, especially in countries where individuals can reach high standards of living anyway, and the alleged extra effort of a STEM degree might not be worth.

A representative from a large-sized Spanish company expected to hire technological profiles, process engineers and IT professionals constantly within the next years. However, he is not confident that the company will be able to find these people. He reported issues regarding this subject in the past. He commented that recently, their company started hiring professionals from Latin America, and they may continue if unable to find in the EU. An employer from a micro-sized Greek company stated that the drawback his company is expected to face regarding the recruit of a high-skilled employee is relocation, as many ideal candidates have usually moved abroad. The head of operations of a medium-sized IT company added that as innovation is constant in their field, they would need to find more people. According to her, the market will be in high demand of STEM skilled profiles. She is confident that they will be able to fins these people, maybe not with the specific profile they would like but people able to learn and to fill these needs. A representative of a small-sized Slovenian company indicated that, in his opinion, the ability of recruitment depended on different factors: payment, location of the workplace, attractiveness of the industry, general public and awareness of the brand/company among others. He also predicted that it will be less difficult to attract talent in the future. Finally, one representative of a large-sized Slovenian company stated that the company will be hiring a lot of professionals in the future, particularly specialists on automation, production, future developments and project leaders. He was very confident for the future. He added that in the last career fair they hosted they had a great response, and a growing interest from female candidates.

# 4 Innovative practices and main initiatives to foster STEM

## 4.1 Background

Throughout the literature, a substantial issue arises about factors helping to predict student intentions to **pursue a STEM career** once completed high school. Since in the studies surveyed there is no clear gender distinction, it is assumed here that factor examined add to and/or interact cumulatively with those examined in the previous paragraph. In Youngblood, T.D., Yeter, I.H., Williams, C.M., Burley, H. (2016), using student's participation ad assessment of a specific engineering program, student's motivation to pursue a STEM career was put under scrutiny. Program evaluation data were collected via a student questionnaire and a multiple regression model was set up to predict students' inclination to choose a STEM career. The main predictors within this model were teamwork, overall student evaluation of the program, and problem solving.

A survey of 2458 pupils was used in Chachashvili-Bolotin S., Milner-Bolotin M., Lissitsa S. (2016) to show a positive association between meaningful and stimulating learning experience during high school and pupils' willingness to choose a STEM subject at College. By the same token, the study showed that a positive experience in studying advanced science courses at the secondary school can partially reduce the gender gap and eliminate family background's negative effect as to pursuing a STEM subject. Interestingly, the study showed also that outcome expectations and self-efficacy beliefs have a positive correlation with students entering tertiary education but don't entail differentiations among their interests in the fields of study.

Another crucial question is to detect and assess factors helping students to decide to **remain in a STEM program**. A qualitative study of a cohort of 15 STEM students in a scholarship program showed that students are unclear about 1) the expectations of a research based science career, 2) the breadth of science careers, and 3) the path necessary to reach a career. Positive outcomes were obtained by getting students involved with practicing scientists. Through this engagement, they came to 1) identify a potential career path, 2) accept the uncertainty of a career path, and 3) better understand how they can have a role in the science community (Sweeder, R.D., Strong, P.E. 2013). The reverse side of point 1) 2) 3) – which was not paid much attention in the literature - is the risk of unrealistic expectations due to highly competitive and demanding degree programs. In Hall, N. C., Sverdlik, A. (2016) the outcomes of a motivational intervention on 52 college students in STEM degree programs are presented. Students were asked to consider the possibility of academic setbacks and the importance of downgrading one's expectations to cope with them. Surprisingly, according to post-test measures administered 4 months later, the intervention was unsuccessful. There was no significant improvement in emotional well-being nor a scaling down of goal orientations. Pupils showed even increased expectations and this translated in a and lower GPAs over five subsequent semesters. Authors underscore that such paradoxical effects require further larger-scale research on the nature of students' responses to potentially ego-threatening programs in STEM disciplines.

#### 4.1.1 Inquiry-based learning and expertise of teachers

Pedagogical research seems to prove that interest in STEM subjects must be created and enhanced in primary and secondary school. At the undergraduate level, further interventions are needed to retain student and eschew lack of motivation to pursue a STEM career. Thus, research on the subject stresses interventions that can be done within different scopes and on different level with different targets. With regards to increasing interest in subjects that often are depicted by pupils as abstract and boring, inquiry-based learning, with a strong emphasis on practical experiences, experiments and connections with real world and technological problems is deemed fundamental by all governments' teaching policies (Kearney, 2016) together with a strong emphasis on socio-economic aspects of science. Unsurprisingly, current research reveals also that one of the most important determinants of what students learn is the expertise and pedagogy of the teacher (Ragusa, 2012). Thus, as showed in detail the previous paragraph, improving skills of teacher and updating their knowledge and competencies is one of the primary concerns of governments' intervention to overhaul teaching degrees in all European nations.

#### 4.1.2 Psychological and behavioural nudges

Literature stresses various psychological and behavioural aspects that must be addressed to avoid lack/loss of motivation in pursuing a STEM career. Providing pupils with a clear insight of what a STEM career consists of and implicates can be very helpful to capture their attention and curiosity and shape an interest in STEM subjects. This should be done as earlier as possible in learning trajectories, best according to certain authors, in the middle school. Various activities can be used to introduce STEM subjects as experiential learning through **hands-on/real-world projects, classroom and laboratories activities, speakers, campus trips** and **workshops** (Burwell-Woo C., Lapuz R., Huang T., Rentsch N.P. 2015). Improving pupils' self-confidence and self-efficacy at every stage of their career is no less important. Pedagogical practice suggests that such factors should be regularly monitored and reestablished so that they don't wither away during learning trajectories. Teachers, parents, mentors, counselors and peers can play an important role and have a deep impact on students' self-efficacy and persistence in STEM (Charleston L., Leon R. 2016). Specifically, at undergraduate and graduate level,

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significant literature emphasizes the importance of mentoring to enhance individuals' professional success. Individual and small group mentoring is a very effective strategy to boost student motivation and notably to regularly check their development and retain them in their STEM learning trajectories. Graduate students report both psychosocial and instrumental benefits from their mentoring relationships. (Wheeless A., Blaser B., Litzler E., 2007). The shaping of STEM identity through involvement in faculty activity seem also has a remarkable impact on motivating and retaining students in STEM (Callahan J., Pyke P., Shadle S., Landrum R.E. 2014).

*Table 11: STEM and gender uptake*

*As mentioned above, **gender segregation** in STEM persists. Its roots include awareness of what graduate school entails and the fear of failure (Gruenbacher D.M., Natarajan B., Pahwa A., Scoglio C., Lewis C., Muguira M., 2007). The literature addressing this problem emphasizes some specific interventions that seem crucial for future pursuing of STEM career by girls: 1) an early involvement of girls in STEM subjects since the middle school; 2) more focused and intense form of mentoring; 3) use of **role models**; 4) working with **families** to promote STEM; 5) focusing on **specific groups** of girls (Broadley, K. 2015).*

*As to mentoring in particular, a paper of Irvin K., Hiteshue E., Lanzerotti M., Langley D., Martin R., Geselowitz M., Cerny C.L., Paul B., Chattopadhyay B., (2016) examined the result of an intervention where the **mentorship** is provided to students when they identify and interview female STEM leaders whose careers correspond to students' interests and desired career fields. Koch M., Georges A., Gorges T., Fujii R. (2010) studied some structured interactions between girls and IT female professionals envisaged to encourage girls' IT fluency and interest in mathematics as well as exploration of STEM careers. Program was evaluated administering a pre-post test which revealed that even with limited interactions, girls' expectations of success and attitudes about STEM careers were influenced by interaction with female professionals.*

*Another study identified four relevant factors concerning girl's willingness to pursue a STEM career: 1) confidence in their own STEM abilities, 2) their self-assessment of STEM competencies, 3) their self-assessment of knowledge about university studies and jobs in STEM, and, of course, 4) their academic elective intentions. In addition, the study examined whether participation in the mentoring program and use of the online platform had an impact on any of them. The results indicate an improvement of all four, whereas girls from the control group did not show any. (Greindl T., Schirner S., Stoeger H., Ziegler A., 2013). Also intense and prolonged contact with specific schools where a group of girls is singled out for STEM presentation and activities can have positive outcomes (Gruenbacher D.M., Natarajan B., Pahwa A., Scoglio C., Lewis C., Muguira M., 2007).*

### 4.1.3 Extracurricular activities

Various surveyed articles emphasize the importance of extracurricular activities all along pupils' path from primary school to university. STEM extra-curricular activities are significantly more effective in increasing the amount of STEM pupils than further work in the classroom. They help students pin down and develop interests as well as gain the experience important for careers (Garg S. 2015). Among extracurricular activities there are **summer programs** and **summer camps** that seem particularly fit to enhance and implement the concept of inquiry based teaching and the connection between theory and its practical and technological applications. Summer programs have many positive effects on students. They help students socialize in scientific research environments and cultures which, in turn, bolsters confidence and thus facilitates and encourages continuation into science graduate programs and in STEM careers (Brown C., Russell C., Long H., 2010).

As to secondary school, summer programs, such as camps, provide students with Learning experiences in an informal STEM educational setting. These settings are quite helpful to improve secondary students' awareness of STEM subjects and careers along with increasing enthusiasm, self-efficacy, and content knowledge. This can result in increased achievement, self-efficacy, and interest in STEM along with encouraging students to pursue STEM careers (Nite S.B., Margaret M., Capraro R.M., Morgan J., Peterson C.A., 2015). As to elementary and middle school, participants reported that most of the proposed activities positively affected their interest in STEM subjects. According to parents and guardians as well, student subject-matter interest was considerably enhanced by following the camp. Significantly, outcomes point out that inquiry-based but non-mathematical STEM activities were most successful at stimulating interest (Douglas Dillivan K., Dillivan M.N., 2014).

#### 4.1.4 Digital resources for STEM

Digital resources can be helpful for teacher and pupil training. As extensively reported and previously mentioned in Kearney (2016) governments, through educational institutions and agencies, have paid considerable attention to enhance online teachers training in various forms that can indirectly be helpful to raise young people interest in STEM subjects. Basic traditional approach consists of online instructional materials to be used by teacher. Its efficacy and fruitfulness seem connected to the wider framework where they are used in as specific learning program, to constant monitoring by teachers and to connection with real word situations. An example among many others – but with noteworthy features, although in an overseas context - is the three-year US National Science Foundation Advanced Technological Education (NSF-ATE) project.

A comprehensive series of online multimedia PBL instructional materials - referred to as "STEM PBL Challenges" - was set up in close collaboration with industry and government. Mentioned "challenges" were envisaged to face secondary and post-secondary students with authentic real-world problem- solving concerning a broad range of contemporary issues of sustainability including solar and wind energy, clean water, energy efficient lighting, sustainable agriculture, and "green chemistry" in personal care products (Massa N., Dischino M., Donnelly J.F., Hanes F.D. 2011). A more innovative approach is that of practical learning activities through Remote Access Laboratories (RAL). RAL permit offsite control of state-of-the-art science and technology experiments. Such learning activities, broadly used in universities, can also provide further learning opportunities in secondary schools. RAL can also be adapted to better support enquiry based learning in the context of STEM education. (Maiti, A., Maxwell, A.D., Kist, A.A., Orwin, L. 2014).

In addition, some unconventional approaches are discussed in the literature such as the development and use in the classroom of computer gaming and simulations for instructional purposes, throughout 12th-grade school specifically in the STEM areas (Ormsby, R., Daniel, R., Ormsby, M. 2011). Within this approach, computer games can be used by educators as an instructional tool to create participatory learning activities, assess pupils' understanding of complex situations, help critical thinking and problem solving attitudes, and enhance active engagement (Hyatt K.J., Barron J.L., Noakes M.A. 2012). Another innovative approach is that proposed in (Carmen, C. L., Groenewald, B. 2015) which exploits social media to promote STEM education. Using as matching criteria similarities of demographics and interests. Twitter college student users have been coupled with diverse LinkedIn STEM professionals through a ranking algorithm. The aim is introducing career and role models with similar interests and demographics. This should boost students' interest in STEM related fields and inspire emulation of the models. Assessment on 2000 real college students seem to prove the accuracy of the proposed ranking algorithm.

## *4.2 Innovative features of STEM programs*

One factor highlighted in the literature on STEM uptake (e.g. Essinger et al., 2010) is the broader societal **dichotomy between creative and technical fields** which, according the authors, represent a neglected cause of the relative scarcity of pupils attracted by STEM studies. Many students with interests in the creative and performing arts have the potential to be successful in STEM subjects, but often rule out pursuing careers in STEM and choose humanities, because they view them as two irredeemably split domains/worlds. Through the design and implementation of different inquiry-based labs and focusing on of topics as image processing, robotics, bioinformatics, and audio processing, authors have tried to develop a program focused on the relationship between **creative and performing arts** and broader STEM concepts, aiming also to partially overcome the widespread belief of a radical and intrinsic incompatibility between the two subject-matters. Eventually, other factors helping attract young people into STEM are more traditionally, grants and scholarships expressly tailored to boost and develop pupils' potential in STEM subjects. Another element is the possible connection between **STEM and entrepreneurship**. In this vein, The Young Entrepreneur and

Scholar (YES) program is a program wherein a partnership has been established between a northern American College of Engineering & Computer Science and a College of Business Administration of a public university in the same area. Results don't seem significantly different from those ensuing from other initiatives mentioned above: real-world experiences, gains in self-confidence clarification of career and goals and creation of networks of friends and professionals sharing interests and activities (Massi L., Georgiopoulos M., Young C.Y., Ford C.M., Lancey P., Bhati D., Small K.A., 2013).

The **analysis of STEM curricula** undertaken from the world's leading STEM universities clearly shows that many of them include, to different extent, interdisciplinary courses in STEM programs, in addition to dedicate interdisciplinary undergraduate programs. At the Massachussetts Institute of Technology (MIT), all undergraduate students must fulfil a **Communication Requirement**[12] by completing four courses that teach written and oral communication skills. Two courses (CI-H) are chosen from the Humanities, Arts, and Social Sciences curriculum, providing students with instructions, practice, and feedback in communication skills, and are aimed at achieving clarity in writing; facility in oral communication, and the ability to structure a persuasive argument. The other two courses (CI-M) are major-specific and teach the specific forms of communication needed for the field's professional culture.

Stanford University has a **Technology in Society** (TiS)[13] requirement for engineering and computer science undergraduates, aimed at giving an understanding of their profession as a social activity. Courses are at the interplay between technology and society, and include Technology Entrepreneurship (ENG 145), Ethics in Bioengineering (BIOE 131), and Computers, Ethics, and Public Policy (CS 181). At the University of Cambridge, all engineering undergraduates must study, at their second year, a compulsory **Business Economics** course [14]. In addition, elective courses include **Manufacturing and Management**, which covers the aspects related to the commercial exploitation of a technology-based innovation, as an entrepreneur or within an existing business[15]. The

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[12] Undergraduate Communication Requirement_ About. Available at http://web.mit.edu/commreq/index.html (retrieved 15 December 2016).

[13] Approved Courses - Undergraduate Engineering Handbook. Available at http://web.stanford.edu/group/ughb/cgi-bin/handbook/index.php/Approved_Courses (retrieved 15 December 2016).

[14] Engineering Tripos Part IB, 2P8_ Introductory Business Economics, 2016-17 _ CUED undergraduate teaching. Available at http://teaching.eng.cam.ac.uk/content/engineering-tripos-part-ib-2p8-introductory-business-economics-2016-17 (retrieved 15 December 2016).

[15] Engineering Tripos Part IB, 2P8_ Manufacturing and Management, 2016-17 _ CUED undergraduate teaching. Available at http://teaching.eng.cam.ac.uk/content/engineering-tripos-part-ib-2p8-manufacturing-and-management-2016-17 (retrieved 15 December 2016).

University of California at Berkeley has a **Humanities and Social Sciences** (H/SS)[16] requirement for engineering students "to promote a rich and varied educational experience outside of the technical requirement for each major". Such requirement includes at least two courses on **reading and composition skills**, and at least two from one of the following areas: Arts and Literature; Foreign Language; Historical Studies; International Studies; Philosophy and Values; Social and Behavioral Sciences. Engineering undergraduates from the University of Oxford take courses that connect technology and society, such as: Technical Writing and Communication Skills; Engineering Ethics; Safety and Risk; **Engineering, Sustainability and the Environment**.

At Harvard University, all STEM departments and courses belong to the **Faculty of Arts and Sciences** (FAS), therefore allowing for a broad education in the social, natural sciences and humanities. All students take half of their courses from their major (Concentration), one quarter from electives of their choice – including a writing course - and one quarter from the **General Education program**[17], designed to broaden students' "intellectual perspective": Aesthetic and Interpretive Understanding; Culture and Belief; Empirical and Mathematical Reasoning; Ethical Reasoning; Science of Living Systems; Science of the Physical Universe; Societies of the World; The United States in the World.

In addition to interdisciplinary course requirements, some universities provide the opportunity for dynamic degree programs that combine STEM fields with other elements. For example, the **Science, Technology, and Society** program at the MIT attempts to "increase understanding of the human-built world", where "science and technology have broken through walls of industry and of the laboratory to become an inextricable determining element of nature, culture, and history"[18]. Likewise, the Stanford program of the same name[19] offers **at the same time a Bachelor of Arts and Bachelor of Science** degree. Its faculty represent departments of Anthropology, Communication, Computer Science, Education, Electrical Engineering, History, Law, Management Science and Engineering, Political Science and Sociology, and aims at providing an understanding of the technical and social dimensions of science and technology. At Harvard, the program on Science, Technology and Society is taught at the Kennedy School of Government, and "provides unique resources for coping with the resulting challenges for **scientific and technological innovation, civil liberties,**

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[16] Humanities and Social Sciences _ Berkeley Engineering. Available at http://engineering.berkeley.edu/student-services/degree-requirements/humanities-and-social-sciences (retrieved 15 December 2016).

[17] General Education _ Harvard College. https://college.harvard.edu/academics/planning-your-degree/general-education (retrieved 15 December 2016).

[18] Home – MIT STS. Available at http://sts-program.mit.edu/ (retrieved 15 December 2016).

[19] Science, Technology, and Society: Home. Available at https://sts.stanford.edu/ (retrieved 15 December 2016).

**informed citizenship, and democratic government**"[20]. Finally, the University of California at Berkeley offers an undergraduate **Course Thread on Sciences and Society**. Based on the premise that "the pressing problems of our time are simultaneously scientific and social, technological and political, ethical and economic", the Course Thread helps undergraduates investigate the relationships between these perspectives, for example to understand "how science, technology, and medicine change our horizons of political possibility (as with social media and revolution) and social (in)justice", or "how social and ethical commitments, historical processes, and political formations help shape what will count as authoritative knowledge and viable technologies"[21].

## 4.3 European innovations for STEM uptake

Most European countries consider STEM education a priority (Kearney, 2016). To address this priority, some have elaborated strategies at a national level, while others do not have a unique strategy but more varied ones. Anyway the whole of this strategies are centered on some key points. First, STEM curricula should be strongly enhanced both at primary and secondary level. Secondly, in order to become more attractive for student, STEM education should undergo some rearrangements as to content and method, as it seems uncontroversial that what determines student's enrolment in STEM subjects is the way it's taught at school (primary and secondary). Thirdly, the core of new teaching should be inquiry-based, with a strong emphasis on socio-economic aspects of science. Inquiry based methods enhance pupils' transversal skills like working in groups, problem solving written and verbal expression. The teaching of socio-economic aspects of STEM can effectively be carried out by putting strong emphasis, throughout school lessons, on the connection of science and technology with everyday life (economic development, improvements of life conditions and so on).

Lastly, European agenda insists on the prominence of the concept of Responsible Research and Innovation (RRI) for STEM education and on the necessity to make it part and parcel of teachers and pupils formation. RRI is so defined in (Kearney 2016, p. 9): "Responsible Research and Innovation (RRI) is a process where all societal actors (researchers, citizens, policy makers, business) work together during the entire research and innovation process in order to align outcomes with the values, needs and expectations of society. Overcoming complex societal challenges in an interconnected, globally competitive world, will require all citizens to have a better understanding of science and technology if they are to participate actively and responsibly in science-informed decision-making and knowledge-based innovation". Nevertheless, contrary to

[20] Program on Science, Technology and Society at Harvard. Available at sts.hks.harvard.edu (retrieved 15 December 2016).

[21] Sciences and Society _ Course Threads. Available at http://coursethreads.berkeley.edu/course-threads/sciences-and-society (retrieved 15 December 2016).

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the first two points, on which a considerable effort is being made by all surveyed nations, a substantial deficiency is reported by almost the whole of them in promoting the uptake of RRI tenets. According to Kearney (2016) several types of public interventions for STEM can be identified, including:

1) initiatives addressing situations where a fast recruitment of STEM teachers is a priority;
2) more general initiatives related to initial teacher education;
3) initiatives related to in service teacher education.

Kearney points out that most countries are more committed to improving the professional development of in service teachers than investing resources in STEM specific initial teachers' education.

#### 4.3.1 STEM teacher recruitment initiatives

In UK, a massive investment was carried out in 2015 to increase the number of math and physics teachers, establishing financial incentives and fast track courses to get former teacher back into teaching activities and to attract top graduates into a teaching career. The Netherlands launched an intensive two-year traineeship program aiming to get more educated teachers into the classroom. In the program, top university graduates work for some days a week as secondary school teachers.  By completing the program, they obtain a teaching qualification and, in addition to teaching training, during the two years they participate to an intensive business leadership program. Two other programs allow participants to work as professionals in tech industries and at the same time teaching in general secondary or vocational education. This aims at making teaching significantly more up-to-date, more diverse and interesting for their pupils. Denmark has tried to offer more attractive and varied curricula to students – who will get qualified in teaching not only in math but also in three related subjects to be chosen among biology, chemistry, physics, geology - stressing at the same time that they will gain a job quickly. Other countries have to face expressly the lack of students choosing a teaching career. To face this problem, Hungary offers scholarships, whereas Switzerland has introduced "professional transfer" which allows STEM professional with non-teaching background to become teachers at specific conditions. In 2015, France launched a vast and broadly advertised recruitment campaign. Latvia also created new teaching curricula with specific facilitation for new students. Finland and Sweden as well show a prospective potentially dramatic shortage of teachers, since most of them are already fifty years old. In Finland no specific initiatives have been envisaged to address this problem. Sweden, on the contrary, has rolled out a two-year program where young people with a degree in any STEM subject are recruited and placed directly in school where they work part time and at the same time study at distance for their teaching.

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#### 4.3.2 STEM teacher education initiatives

The UK and Malta have introduced new degree programs to enhance the study of science and to render a career as STEM teacher both procedurally easier and more enticing. Specifically, the UK has launched a physics degree which allows students to study their topic of interest and at the same time to become a qualified teacher without attending an additional year of teacher training. In Lithuania, a bachelor's degree is offered covering pedagogy, chemistry, and physics. The Netherlands, through the so-called "Dutch Technology Pact", has established that all primary schools must incorporate the teaching of science and technology into their curriculum by 2020. Estonia, Austria, and the Flanders region of Belgium have also set up a network of collaboration which has brought to the incorporation of innovative pedagogies. Noteworthy is the Flanders case that through the University of Leuven has elaborated new forms of didactics, which have to be integrated in new curricula. Several initiatives targeting primary and secondary school teachers have set up communities of practices made up of schools whose teachers meet regularly to evaluate didactics. In addition, general reforms in initial teacher training can have an impact on future STEM teachers. The UK government, within the aforementioned attempt to invest in STEM teacher recruitment, has decided to grant schools substantial autonomy to steer teacher's education improvement at the local level. Denmark and France have introduced quite similar general reforms into their institutional training for teaching STEM. These reforms stress (1) the enhancement, in addition to subject-specific competences, of a common core covering psychology, pedagogy and didactics, (2) more opportunities for specialization; a flexible module structure, and (3) an international perspective. Notably, in France much attention is being paid both to development of innovative tools and methods (especially with a digital focus), and to deeper forms of collaboration among the various educational actors involved in the teaching path. France has also tried to introduce practical elements bringing concrete experience of teaching in the classroom. This has been done pairing teachers at the beginning of their career with experienced teachers.

An important issue addressed in Kearney (2016) is adequacy of initial teacher education available for prospective STEM teachers. Half of countries surveyed, including Austria, Bulgaria, Estonia, Spain, Finland, Croatia, Hungary, Malta, Poland, Slovenia, report that basic aspects of teacher training - capacity of mastering the subject and making it comprehensible to students - are sufficiently covered. Two other areas were deemed sufficiently addressed in initial teachers' formation by 32% of countries surveyed, including Austria, Denmark, Finland, Hungary, Lithuania, Latvia, the Netherlands, and the UK: the capacity to teach (1) scientific modelling skills and (2) argumentation skills. On the contrary, most countries report that other important areas of teacher's formation are substantially deficient and need to be more adequately addressed, notably "knowledge and ability to analyse students' beliefs and attitudes towards STEM", and

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"Knowledge and ability to teach STEM taking into account the different interests of boys and girls. As to the latter, prospective teachers have always neglected gender related interests but now they need being made aware of their impact on students' motivation to study and pursue STEM careers and apprehend methods to face with this issues (European Parliament 2015).

#### 4.3.3 STEM teacher training initiatives

These programs aim at updating - also through specific curriculum reforms – teachers' competence, considering both content and method in order to improve the effectiveness of teaching. In particular, in Poland, the initiative develops tools that allow teachers to use the best methods for working with students, based on experimentation, making and verifying hypotheses, and exploring phenomena through direct experience. In Malta, the PRIMAS project supports inquiry-based STEM teaching through teaching materials, teacher training, and other actions. In Croatia, teacher training aims at increasing knowledge, with an eye on effectively collaborating with external professionals. In Slovenia, bi-annual conferences for science teachers have been carried out. In the UK, professional learning resources have been published since 2014, based on an in-depth analysis of young people's responses to tasks in a survey. Such resources should help practitioners to understand strength and weaknesses.

Another group of countries is changing their training system at the national level. As a consequence, this has impacted STEM teachers in various ways, notably raising requirements (years spent in formation and number of credits) to become a teacher and implementing new kinds of training practices. In Czech Republic, the so-called 'career sySTEM' aims to support teachers' lifelong professional development and is linked to their remuneration. Estonia's initiative focuses on the development of new standards for the teacher's profession, supporting teachers' professional networking. In Malta, training is provided to improve teachers' knowledge, skills, attitudes and practices which can find application in the classroom. In Finland there is a nation-wide ongoing process of evaluating teacher professional development. In the Netherlands, different initiatives aim at providing guidance for new teachers to do their job as part of a professional team, promoting a learning culture, teachers' self-assessment and the continuous updating of skills and knowledge. Finally, new initiatives, the expansion of existing ones, or dedicated funding focus on professional development of STEM teachers. In the Netherlands, a STEM Teacher Academy was created to provide professional development in cooperation with industry. France has widened the outreach of its existing La main à la pâte Foundation (a foundation engaged in promoting STEM at different levels and through different channels), by setting up a national network of "Houses for science" to promote science education, to produce pedagogical material useful for teaching and to help teachers bringing innovation into their science teaching practices. Finland and

Norway (Norway solely for in-service training in maths) fund STEM specific teacher professional development programs both for primary and secondary schools.

#### 4.3.4 Responsible Research and Innovation (RRI)

As remarked at the beginning, a substantial deficiency has been reported in the uptake of the principle of Responsible Research and Innovation (RRI). As observed above, RRI has gained prominence in the European agenda and its enhancement, in addition to being a value itself, could play an important role in attracting young generations to STEM.

Implicit in the reported definition is that people should become aware of social impact of science and technology on different planes to make responsible choices through a better science literacy. Science education has therefore a very important role to play in the promotion of RRI. Yet, the majority of surveyed countries in Kearney (2016) stated that RRI is clearly established in the academic world but remains widely unknown at national level, and that the school community is not familiar with it. Noteworthy exceptions are the Nordics, where RRI seems on the contrary a familiar concept in STEM education. In Danish school curricula, remarkable emphasis is put on sustainability issues and ethical choices related to innovation processes. So topics directly connected with RRI such as the impact of environmental change on biodiversity, society's energy supply, or the development of a sustainable society are presented and discussed in various primary and secondary school classes. Sweden has also put emphasis on ethics in science education in its curriculum, where the issue of responsible research and innovation is addressed.

Swedish guidelines for compulsory schooling curricula are even more ambitious. Seven- to nine-year-old pupils should apprehend the preconditions to envisage and assess technical solutions to issues concerning the economy, the environment, and sustainable development (biofuels, genetic engineering, and the opportunities, risks and ethical questions arising from their application) and also to questions concerning aesthetics, gender roles. In addition to the Nordics, only few countries reported in Kearney (2016) that RRI has become a sound and diffused concept in the context of STEM education and that it is considered a priority or at least important issue at national level. In these few countries, which include Spain, Ireland and Belgium, RRI is either incorporated into the curriculum, or expressed and implemented in national or European projects developed to enhance young people's direct involvement in scientific research. Spain is the only country where the tenet of RRI seems to find the most advanced implementation expressions. Different Spanish programs - run through internet, schools, research centers and science museums - promote Inquiry Based Science Education (IBSE) and the interaction of students with different social actors engaged in Science and technology with the aim to make theme active citizens in the knowledge society.

#### 4.3.5 Online teaching

Online resources have become increasingly popular over the last 15 years and acknowledged as a useful form of professional integrative training. Considerable efforts and investments in this area have been carried out in most EU countries, ranging from development of short one-off webinars, to activities on e-learning platforms (such as Moodle) to full Massive Open Online Courses (MOOCs), to the use of blended online and offline approaches. Emphasis seems to be placed on the pedagogical use of ICT in STEM teaching and learning services mentioned mainly target in-service teachers. France, Italy, Austria and Bulgaria have developed a common platform collecting all the online professional training materials available at national level, thus making it easier for teachers to access. Czech Republic and Lithuania do not yet have a national strategy to support online professional development but plan to have one soon and/or have for the moment independent local level strategies.

# 5 Societal challenges and recommendations

During the validation workshop, participants were presented with the forecasted rise of STEM demand, as presented in the previous chapters. This forecast leads to three alternative scenarios. In the first scenario, STEM supply either falls, stays the same, or increases - but less than demand. As a consequence, there is a **shortage** of STEM supply, meaning that there are more STEM jobs than graduates. In the second scenario, supply keeps pace with demand and, thus, the **equilibrium** is maintained. In this, the number of STEM jobs matches that of STEM graduates. In the last scenario, the growth of STEM supply surpasses that of demand, creating a situation of **surplus** of STEM supply, in which there are more STEM graduates than jobs. Participants were requested to **identify the challenges** that the scenario posed **to universities, the private sector, and the government**. Then they were asked to **suggest recommendations** for **each of the three sectors** to help them face the challenges.

## 5.1 Challenges

#### 5.1.1 Supply shortage scenario

This scenario is delicate for universities, which face the challenge of not providing enough graduates to cover the labour demand in the STEM sector. This fact might be due to a **low enrolment** in STEM degrees and/or to a high number of **drop-outs**. Low levels of enrolment could be caused by a lack of communication with lower educational levels such as high schools or vocational training centres, which could otherwise foster the transfer of students from these schools to a STEM university degree. Similarly, a lack of communication with private companies might have a negative effect on enrolment

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and graduation. It might also deter universities from realising that the demand of STEM graduates is rising more than its supply.

Apart from reducing the pool of potential graduates, low enrolment might bring financial problems to universities. There exists the possibility that this shortage of supply concerns only one or some subjects within STEM. Therefore, specific interventions will be required for them. Even if universities enjoy good levels of enrolment in STEM disciplines, they might still have a problem of graduate shortage due to drop-outs. The underlying causes for this could be a lack of interest or motivation for finalising the degree, or not having enough skills or support to cope with a demanding coursework.

On the other hand, the private sector also faces important challenges, the most important being the **lack of employees**. Except if the economy is in full employment, they would have access to workforce specialised in other sectors, but they would lack employees with the key STEM skills. In addition, companies might also lack employees with soft skills. This situation might be due to a **gap between universities and companies**, and the inexistence of a proper communication between the two sectors to discuss, for example, about the practical application of knowledge or to facilitate that graduates meet employers' needs.

Finally, from the point of view of the government, the main challenges would be the risk that **industries relocate** to countries with higher STEM labour supply. This together with the fact that the STEM sector would experience problems to enrol qualified staff, could negatively affect the competitiveness of the EU STEM sector, and, by extension, of the whole EU economy. Another issue could be that new STEM disciplines (probably more linked to the current needs of the private sector) need a long and bureaucratic process before obtaining the accreditation.

### 5.1.2 Equilibrium scenario

This scenario can seem an ideal world because demand and supply match, nonetheless some challenges were also identified. For example, even if there are just as many STEM jobs as STEM graduates, employers can have **difficulties in finding the specific profile they are looking for**. In this context and to minimise the prevalence of a mismatch of skills, universities face the challenge of how to adapt their curricula to the needs of firms. For example, participants indicate that at the moment there is often a lack of communication skills among STEM graduates. Furthermore, there is currently no follow-up of students once they graduate, and the communication between universities and high schools is scarce. This can pose difficulties for students and could stop them from seeing the different levels of education and the access to the labour market as a continuum, which could place a higher degree of uncertainty to their future.

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Another challenge identified in this situation is that of **widening the scope of STEM discip**lines in order to embrace other sectors that could apparently seem unrelated. Similarly, it would be a good opportunity to deal with the gender imbalance within some STEM disciplines. In addition, universities would always have the challenge of offering excellent education and providing high-skilled professionals.

If there are enough STEM graduates but also a mismatch of skills, employers in private companies will face the challenge of **having workers that lack some key skills**. These might refer to problem solving abilities, soft skills (teamwork, management, communication, ability to address the job market, etc.), as well as to scarce working experience. Related to this, it could be difficult for firms to find employees with both technic and managerial skills. Recent STEM graduates might have a solid technical background but they often lack managerial skills, which could be an issue if in the future they need to take up a management position. On the other hand, graduates in business administration or related subjects could be employed for work placements in management, but they would lack a deep knowledge of the firm's core activities.

This situation of equilibrium can disappear, and move to either direction (shortage or surplus of supply). Thus, the government has the challenge of **being prepared to act in the event of any imbalance** in the STEM labour market. Some mentioned that another challenge that governments currently face and that could also exist in a situation of equilibrium is the lack of involvement of STEM experts in policy-making. Moreover, since the expansion of the STEM sector could be considered convenient for the EU (for example to foster its competitiveness or to deal with societal challenges), the government would always have the challenge to promote STEM among a wider population, referring both to pre-university students (supply) and employers (demand).

It must be noted that in some countries the government does not have much power to intervene in universities' internal matters. For example, the government it is not allowed to impose changes in the university curricula. Furthermore, sometimes firms might be reluctant to search for governmental support due to bureaucratic requirements.

#### 5.1.3 Supply surplus scenario

In this last scenario, universities face a situation in which part of their graduates cannot find a job, or a job in the STEM sector. Here universities might have the challenge to provide STEM graduates with business skills in order to increase their employability. Universities might also **lack strong links with industry** that could facilitate the transition from graduation to the labour market. Moreover, connections might also be weak within higher university institutions, both within and across departments. Universities face as well the challenge of adapting to the changing job market, that is

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demanding less STEM employees (compared to the number of graduates) than in the past.

The private sector enjoys, apparently, an ideal position, because it has a large pool of graduates from which to select its employees. However, this might be covering a situation in which the STEM sector has a **low share of the whole economy**. This might hinder EU's industry **ability to compete** in the global market.

Public authorities face the great challenge of unemployment among part of the population (STEM graduates). Depending on the situation in the other sectors of the economy, these graduates might be able to find jobs but they might be not perfectly suited to their STEM skills. This would create a situation of **skills mismatch**, which implies that the connection between the graduate and its job placement is not optimal. Moreover, since STEM graduates are usually highly qualified they might be overskilled for these jobs, which can create dissatisfaction among them. Another challenge that governments would face is how to keep regulation updated in order to facilitate cooperation between stakeholders.

*Table 12 Challenges for universities, the private sector and the government in STEM scenarios*

| | Shortage of STEM supply | Supply-demand Equilibrium | Surplus of STEM supply |
|---|---|---|---|
| **Universities** | - Low enrollment<br>- Dropout rates | - How to adapt curricula to the needs of firms<br>- To expand the scope of STEM<br>- Gender imbalance | - How to provide STEM people with business skills<br>- How fast can they adapt to the changing job market |
| **Private Sector** | - Lack of employees<br>- Gap between universities and companies | - Graduates that lack soft skills and working experience<br>- Difficulty to find employees with both technic and managerial skills | - How to compete in the global market |
| **Government** | - Loss of competitiveness versus third countries<br>- Industry leaving to countries with high STEM supply | - How to act if the equilibrium disappears<br>- Lack of involvement of STEM experts in policy-making<br>- Promote STEM among a wider population | - Unemployment<br>- Skills' mismatch |

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## 5.2 Recommendations

### 5.2.1 Shortage scenario

Several suggestions have been put forward to face the above mentioned challenges. For the universities it's recommended to **promote a positive image** of STEM sciences with the aim to increase the number of graduates. Moreover, in order to decrease the number of drop-outs it could be convenient to **lower the intensity of educational demands**. Finally, universities should increase their cooperation with other stakeholders. Contacts with the industry could help to adapt the academic curricula to the current state of affairs in STEM. For example, private sector experts could be involved in the design of the educational content, which could also add subjects not directly linked to STEM, such as management, law and business. This could help to address the current lack of understanding of the private sector and limited commercial mentality among academics and graduates. Moreover, **collaboration with the private sector** could facilitate the organisation of internships for STEM students in firms operating in this sector. Universities should also contact national institutions and encourage them to promote STEM sciences, especially among high school students. Furthermore, within the academic sector it would also be convenient to increase the cooperation between scientists and teachers.

In order to fight the problem of not finding enough employees, **private companies could undertake actions to promote STEM** disciplines in universities and society in general. They should present their activities at university events, for example during the universities' open days or in conferences targeted at high school students. In addition, they should **communicate their current specific needs** as well as those that they expect for the future both to the universities and the government, so that they could carry out actions to cover them. Participants stressed that there must be more cooperation among firms operating in the same STEM field, in order to have a stronger voice when communicating the common needs. This cooperative mentality should gain importance versus that of competition.

Moreover, in order to increase the attractiveness of STEM degrees, it was suggested that business owners should be part of the education process, that they should invest in university equipment, and that they should offer appealing internships to students. This could also increase students' motivation for finalising their degrees and pursue a professional career in STEM. As said before, companies could be involved in the design of the academic content, for example, emphasising the need to teach also soft skills. Finally, it is very important that the **employment conditions improve** to avoid that this could act as a barrier for choosing a STEM discipline as a professional career. This would imply looking at the salary, the working hours, the conditions for taking leaves (sick, holidays, maternity, etc.), the flexibility to conciliate work and private life, etc.

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The government should also collaborate, as the universities and the private sector, in promoting STEM among society. For instance, they could **launch campaigns** providing a positive view of STEM sciences or support the inclusion of citizen science in schools and public life. For some STEM disciplines (mainly computing and engineering), part of the actions should focus on women, in order to close the gender gap that exists in them.

Another action that was suggested was to increase the **investment in scientific research**. Concretely, it was mentioned that governments should develop a long-term strategy for investment in research. One specific action could be to aid STEM students to fund their degrees, for example increasing the number of grants available. The government could also finance the chambers of commerce in order to foster smart specialisation.

Public authorities can perform a mediator role to **facilitate the connection between universities and the private sector**. This could help to align education with companies' needs, for example through increasing flexibility and allowing businesses to be involved in the educational process. Moreover, public authorities could give support to graduates in the transition between the university and the labour market. One option could be to pay the salaries of interns or new graduates employed in private companies.

Finally, it is paramount that governments put efforts to **streamline the bureaucratic processes** related to higher education. Bureaucracy should not be a barrier for implementing changes in universities' curricula to adapt them to the needs of the private sector and society in general. For example, public authorities should ease the process of accreditation of new STEM disciplines. In addition, they should allow the requalification of degrees, also in the third educational period.

### 5.2.2 Equilibrium scenario

Under a scenario where demand matches supply, **universities should teach soft skills** (communication skills, critical thinking, ability to adapt, etc.) to adapt their curricula to the needs of the firms, and they should also search feedback from companies when designing their curricula. They should also have constant contacts with enterprises and collect their needs in order to reflect this in their teachings. Moreover, they should transmit to students not only technical and soft skills, but also useful information for finding a job, preparing a CV, etc.

On the other hand, to expand the scope of STEM it would be necessary that STEM **university departments increase openness to society** and that they allow to combine their degrees with those of other faculties such as humanities, history, design, big data, etc. Acquiring design skills could be useful for the fabrication of some products, such as cars, and to offer more personalised solutions to consumers.

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Having a stronger relationship with STEM firms would help to follow-up graduates once they have finalised their degree. Apart from this, universities should also work side-by-side with high schools in order to facilitate transition from secondary education to university. Both institutions should work together in order to match high school students' interests with university degrees. In fact, some old departments are starting to change to achieve this goal, and they are combining departments and courses.

In order to increase the chances of finding graduates that meet the skills required by employers, private companies should maintain a **solid connection with universities**. With this, they can communicate universities which skills are they looking for, they can be involved in academic courses, and they can implement traineeship programmes for students or recent graduates so that they can be immerse in a working environment as soon as possible. The latter could help to address the problem of scarce working experience among young STEM graduates. The cooperation between these two actors was perceived as key and it was stressed that academia and industry should never be seen as two separate worlds.

Since it is not guaranteed that the equilibrium will last forever, industry should try to do **future forecasts** to assess, for example, if they will need more demand and what kind of skills will they require. According to this analysis, they should interact with universities to design new degrees that create new possibilities for both stakeholders. Moreover, the private sector could contribute to deal with the issue of women underrepresentation in some STEM subjects by taking actions to guarantee the balance between work and private life. For example, in ICT this balance could be facilitated by offering the option of tele-work.

One of the actions that the government could do to spread STEM among a wider population, is to support and promote **vocational training related to STEM**. This would show that education in STEM related areas can be attained in other settings than universities and do not always require the pursuit of long and demanding university degrees. In addition, graduates in other areas can also become acquainted with STEM, for example, graduates in business that want to manage a high-tech start-up. Participants considered that this diversity in job options related to STEM would be beneficial.

The government sometimes cannot intervene, thus, it must rely on soft power to promote changes in the university teaching of STEM or to foster communication between universities and private companies. However, it was deemed essential to involve STEM experts in the decision-making process in order to increase government's ability to act on matters related to STEM and research, to perform forecasts for this sector, and to face the different scenarios. Moreover, it would be optimal if some of them were usually involved in political life in general. Finally, public authorities should also monitor how the

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gender imbalance in each STEM subjects evolves and to collaborate with industry in order to allow for a better balance between work and private life.

#### 5.2.3 Surplus scenario

In order to increase the employability of STEM graduates, **universities should offer entrepreneurship courses** in STEM degrees. This would better equip STEM graduates for creating their own enterprises, without having to rely only on the option of being hired by an existing firm. Moreover, it could improve graduates' preparation for working in STEM job placements, since several employers in this sector report that they miss entrepreneurship and related skills in STEM graduates. In addition, it would make them more capable to work in other sectors in case the job vacancies in STEM are scarce.

Related to this, participants agreed that **more interdisciplinary elements are needed in STEM degrees** and in the university in general. They indicated that more openness between STEM departments would be convenient. In this line, it would be positive to have interlinks between STEM subjects that could seem unrelated, for example medicine and engineering, medicine and materials' science, etc. Moreover, there should also be interdisciplinary degrees combining a STEM discipline with subjects in other fields. For example, in addition to offering entrepreneurship courses in STEM degrees, it was also recommended to provide STEM courses in business schools.

The private sector can also contribute to improving the employability of STEM graduates. They could **offer apprenticeships** to students ranging from bachelor's degree to PhD level, as well as work placements to recent graduates. Firms should increase their links with universities and exchange more information with them. This could help universities to be up to date and to provide their students with the skills required by the STEM market. Banks could also have a key role by providing financial support to start-ups and thus fostering entrepreneurship and innovation.

Similarly, the government could provide **support to start-ups** in the STEM sector, in terms of financial means, counselling, etc. Public authorities could expand the apprenticeships' programmes which should also cover younger brackets, for example those aged sixteen or more that are still not enrolled in a university degree. These programmes can facilitate further employability of STEM graduates. Another option could be to **offer some basic income for scientists** that embark in research in which the expected returns are uncertain. This income would not be tied to the results of their research and would provide them with some stability, and minimise risk aversion.

Other suggested actions include to **upgrade legislation** in order to allow more collaboration between universities, private sector and public authorities; and to introduce a yearly review process of universities to assess the teaching schemes and to take into account what are the relevant trends around the world in this field.

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*Table 13 Recommendations for universities, the private sector and the government in STEM scenarios*

| | Shortage of STEM supply | Supply-demand Equilibrium | Surplus of STEM supply |
|---|---|---|---|
| **Universities** | - Promote a positive image of STEM sciences<br>- Lowering the intensity of educational demands<br>- Increase cooperation with stakeholders (industry, schools, government) | - Include soft skills in the curricula<br>- Combine STEM degrees with those in other faculties | - Offer entrepreneurship courses in STEM degrees<br>- Promote interdisciplinary degrees |
| **Private Sector** | - Promote STEM and communicate specific needs<br>- Involvement in the education process<br>- Improve the employment conditions | - Maintain a solid connection with universities<br>- Facilitate balance between work and private life | - Apprenticeships from BSC to PhD level<br>- Stronger links with universities |
| **Government** | - Promote STEM among society<br>- Invest in scientific research<br>- Facilitate connection between universities and private sector<br>- Streamline bureaucratic processes | - To involve more STEM experts in decision-making<br>- Promote vocational training | - Support to STEM start-ups<br>- Expand apprenticeships' programmes<br>- Provide basic income for scientists |

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# 6 Conclusions

This report presented an overview on the EU and how it is prepared to meet future STEM skills requirements. It is the result of the activities under Task T2.1 “Analysis of Supply and Demand Side of STEM”, T2.2 “Development and validation of the scenarios and trends”, and T2.3 “Definition of educational profiles addressing the labor market needs” of WP2 “Economic and societal dimension of science and technology”. A systematic literature review was undertaken to set a background for the research. Evidence was corroborated through data analysis of official statistics and from the analysis of university curricula. A number of in-depth interviews to European employers have been carried out to better depict the demand side of STEM skills. Finally, a workshop with STEM stakeholders was organized to develop and evaluate potential scenarios.

In the EU-28 there were 5.3 million STEM students in 2014, of which 69% were male and 31% were female. STEM students account for about 27% of all students in tertiary education. Approximately 900,000 students graduated in STEM programs in the EU-28 in 2012. Again, women accounted for 31%, while men accounted for 69%. Graduations from STEM programs accounted for 19% of all graduations. The literature identifies a number of economic, social and cultural factors to explain why students choose a particular field of study. Economic returns to STEM education exceed those to humanities. The choice to pursue STEM studies is also governed by cultural norms and expectations. The way in which science is taught in schools also has an impact on students' choice of study fields. Gender segregation persists across STEM fields. STEM programs from the world’s leading universities offer a rich, varied and interdisciplinary education. Undergraduate programs in STEM fields often require courses such as Entrepreneurship, Business, Ethics, Reading and Composition skills. Many top-level universities also offer dynamic Science, Technology, and Society undergraduate programs, where STEM is combined with other fields.

In the next ten years there will be 8.2 million new STEM jobs in the EU. The skills profiles of STEM workers will need to adapt on the developments and trends of the industries they work for. In addition to industry-specific trends, a number of cross-sectoral factors could further shape the demand for STEM workers. If not enough students will enrol or graduate from STEM degrees, supply will not meet the rising demand for STEM professionals. Universities could promote a positive image of STEM sciences, lower the intensity of educational demands, or increase cooperation with stakeholders. Industry could be more involved in the education process, improvement of employment conditions, and a clearer communication of industry needs. Even if there were just as many STEM jobs as STEM graduates, problems could still arise. Firms should maintain solid connection with universities, and facilitate work-life balance to ease female uptake. Universities should include non-STEM training in their curricula, increase openness to society and combine STEM degrees with other departments. The public sector would need to be prepared to act in the event of any market imbalance, for example by promoting STEM among the general public, or to involve STEM experts in education policy making. If the supply of STEM skills exceeded the number of available STEM jobs, many STEM graduates would not be able to find an appropriate employment. Universities could provide students with business skills, to increase employability, or entrepreneurship skills to help them starting their own business. The private sector could contribute to improve employability, for example by increasing apprenticeships and graduate programs. The government could fund startups and foster innovation, upgrade legislation and periodically review university teaching schemes to account for the changing economic context.

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