

# INTEGRATED STEM TEACHING STATE OF PLAY STE(A)M IT Deliverable 2.1



## STEAM IT

AN INTERDISCIPLINARY STEM APPROACH

Collaborating organisations and initiatives:



EDUCAÇÃO



University of Cyprus





The STE(A)M IT project aims to (1) create and test of a conceptual framework of reference for integrated STE(A)M education; (2) develop a capacity building programme for primary schools teachers and secondary STEM teachers, based on this framework, with a particular focus on the contextualization of STEM teaching, especially through industry-education cooperation, and (3) further ensure the contextualization of the integrated STEM teaching by establishing a network of guidance counsellors/career advisors in schools promoting the attractiveness of STEM jobs to their classes (<http://steamit.eun.org>).

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## INTRODUCTION

Many educational research studies have indicated that students' interest and motivation toward Science, Technology, Engineering and Mathematics (STEM) learning has declined especially in Western countries. Concern for improving STEM education in many countries continues to grow as demand for STEM skills to meet economic challenges increasingly becomes acute (English 2016; Marginson et al. 2013; NAE and NRC 2014). Many education systems and policy makers around the globe are preoccupied with advancing competencies in STEM domains and have engaged in some education reforms. However, the views on the nature and development of proficiencies in STEM education are diverse, and increased focus on integration raises new concerns and needs for further research. Recent reforms in USA (such as Next Generation Science Standards<sup>1</sup>) advocate for purposefully integrating STEM by providing deeper connections among the STEM domains. Such an approach raises issues such as competing agendas between disciplines, lack of coherent effort, and locating and teaching intersections for STEM integration. STEM subjects often are taught disconnected from the arts, creativity, and design (Hoachlander and Yanofsky 2011).

In this light, the aim of this Integrated STEM teaching State of Play, is to provide an overview of the existing scientific and grey literature research on the topic while laying the foundation for the development of the first Integrated STE(A)M education framework. The report presents in detail the results of the SWOT analysis performed on the topic that reveals the opportunities and challenges ahead. The SWOT analysis was then complemented by a questionnaire to collect information on stakeholders' views regarding STEM integrated teaching, available resources, and the barriers to its implementation.

## About the STE(A)M IT project

In order to really get students to see the interest of STEM degrees and careers, and even more importantly, show students, and society at large, the key role that STEM plays in improving our lives and their need for our future, we need STEM to be taught in an integrated way. We need all the components of S (science) to work together. All the letters in STEM to work together. And even better, for all the subjects to work together STE(A)M. We need to apply measures to teach the different disciplines in an integrated way, connected to real life issues. We need "to steam education". If we "STE(A)M IT", we can ensure future citizens will be ready to tackle any issues in society, in a collaborative, critical, and efficient way.

To achieve this, the STE(A)M IT project aims to (1) create and test a conceptual framework of reference for integrated STE(A)M education; (2) develop a capacity building programme for primary schools teachers and secondary STEM teachers, based on this framework, with a particular focus on the contextualization of STEM teaching, especially through industry-education cooperation, and (3) further ensure the contextualization of the integrated STEM teaching by establishing a network of guidance counsellors/career advisors in schools promoting the attractiveness of STEM jobs to their classes.

1. (Next Generation Science Standards, 2020)



## ABOUT INTEGRATED STEM TEACHING

### What is integrated STEM teaching

Moore et al. (2014) defined integrated STEM education as “an effort to combine some or all of the four disciplines of science, technology, engineering, and mathematics into one class, unit, or lesson that is based on connections between the subjects and real-world problems”. Integrated STEM curriculum models can contain STEM content learning objectives primarily focused on one subject, but contexts can come from other STEM subjects. Integrated STEM education could be defined as the approach to teaching the STEM content of two or more STEM domains, bound by STEM practices within an authentic context for the purpose of connecting these subjects to enhance student learning.

In Europe, there is no integrated STE(A)M education framework of reference and the STE(A)M IT project will lead the way in the creation and testing of the 1<sup>st</sup> Integrated STE(A)M framework. More particularly, the objective is to develop more coherence in STEM education by defining collectively with Ministries of Education (MoEs), industry and STEM teachers (via a co-construction process) the concept of integrated STEM education. This will be supported by the development, with a focus group of STEM teachers, of interdisciplinary innovative teaching and learning scenarios that will be used to test the proposed framework of reference for integrated STE(A)M education. In addition, the STE(A)M education movement provides the possibility to develop innovative and creative approaches for interdisciplinary STEM education projects enabling the integration of STEM and non-STEM subjects to be interlinked.

Sanders (2009) described integrated STEM education as “approaches that explore

teaching and learning between/among any two or more of the STEM subject areas, and/or between a STEM subject and one or more other school subjects” (p. 21). Sanders suggests that outcomes for learning at least one of the other STEM subjects should be purposely designed in a course—such as a math or science learning outcome in a technology or engineering class (Sanders 2009). Moore et al. (2014) defined integrated STEM education as “an effort to combine some or all of the four disciplines of science, technology, engineering, and mathematics into one class, unit, or lesson that is based on connections between the subjects and real-world problems” (p. 38).

### Real world challenges

#### What are they

Real-world challenge-solving is a philosophy of teaching and learning, directly connected to problem-based learning (PBL), through which students work together to solve a problem of priority to them and to their community. Real-world challenge-solving can be facilitated by input from experts in the field and access to current knowledge. Students no longer look for a quick or short-term answer. The goal of learning shifts to gaining critical information to solve or resolve an important challenge or concern. Students acquire this knowledge as they research the issue in hand and develop and test potential solutions. The term «real world» is not meant to delineate learning within or outside the school, but rather to emphasize the essence of student ownership of the problem, solution, and learning, and the connection with the larger community (Nagel, 1996).

In an attempt to better define the collective education agenda while also considering ways to make the world fully inclusive for people with disabilities by 2030, the United Nations have raised the issue of inequality and adopted in September 2015 the Sustainable Development

Goals Agenda<sup>2</sup> to work on during the next 15 years.

Based on the Sustainable Development Goals Agenda but not exclusively, examples of real-world challenges that need to be addressed and tackled include:

- Eradication of Poverty and Hunger
- Quality Education
- Gender Equality
- Clean Water and Sanitation
- Affordable and Clean Energy
- Decent Work and Economic Growth
- Industry, Innovation, and Infrastructure
- Reduced Inequality
- Sustainable Cities and Communities
- Responsible Consumption and Production
- Climate Action
- Life Below Water
- Life on Land
- Peace and Justice Strong Institutions
- Partnerships to Achieve the Goal
- The Coexistence of Animals and Humans
- The Effect of Wildfires on a Local Community
- Overpopulation
- Good Health & Well-Being
- Access to Scientific and Technological Breakthroughs

## Addressing the Grand Challenges for Engineering

The continuous technological development that ensures progress in every sector is linked with Engineering, that further depends on understanding and performing well in STEM subjects. The world is currently facing multifaceted challenges that relate to increased demand for sustainable resources, the existence of advanced communications networks and infrastructure systems, as well as improvement of education and healthcare. All

the aforementioned have greatly contributed to the social and economic prosperity the world has known during the past decades, however on the one hand there is a lot of room for amelioration as new challenges keep rising continuously, but also there is an urgent need to tackle inequalities as the vast majority of the interconnected world we live in does not have access to technology and solutions that in the 21<sup>st</sup> century are taken for granted. In addition to the very generally described real world problems in the previous section, a more elaborate list of challenges that find their solution in Engineering is discussed below.

The Grand Challenges for Engineering, as defined by a panel of international leaders and technological thinkers and the National Academy of Engineering (NAE)<sup>3</sup>, and outlined in the respective published report<sup>4</sup>, are a compilation of fourteen challenges that need to be addressed urgently and fall into four main areas: sustainability, health, security, and joy of living. All four, although distinct, are areas that need to be thoroughly examined to improve modern society and our lives. Most importantly, while examining those thematic areas and each of the fourteen challenges individually the connection to STEM subjects is undoubtedly visible. Consequently, the belief that contextualization is of major importance, helping students perceive science, technology, engineering, and mathematics as the tools to be used to comprehend and approach hands-on those challenges.

Today there is an abundance of materials and resources both online and in student textbooks. By providing examples of real-world problems and raising those questions to students, all combined with innovative pedagogical trends like Inquiry Based Science Education (IBSE) and Project-Based Learning (PBL), we fuel their creativity and enhance their curiosity to research and find solutions to those questions. The Grand Challenges for Engineering,

2. (#Envision2030: 17 goals to transform the world for persons with disabilities, n.d.)

3. <http://www.engineeringchallenges.org/>

4. <http://www.engineeringchallenges.org/challenges/16091.aspx>



outlined below, can be part of any integrated STEM teaching lesson or series of lessons implemented as projects, both individually but also combined.

1. Advance Personalized Learning
2. Engineer the Tools of Scientific Discovery
3. Enhance Virtual Reality
4. Reverse-Engineer the Brain
5. Engineer Better Medicines
6. Advance Health Informatics
7. Restore and Improve Urban Infrastructure
8. Secure Cyberspace
9. Provide Access to Clean Water
10. Provide Energy from Fusion
11. Make Solar Energy Economical
12. Prevent Nuclear Terror
13. Manage the Nitrogen Cycle

unfamiliar challenge by using videos, speakers, or field trips.

- ***The challenge should be “doable”.*** For a STEM challenge to be successful, students should have access to the resources, knowledge, and skills they need to solve the problem—and the scope of the problem should be manageable. Engineering solutions for a challenge involving clean energy, such as wind turbines or solar cells, might be realistic. However, tackling a problem involving interplanetary space travel—not so much.
- ***The challenge must allow for multiple acceptable approaches and solutions.*** Teachers should not even consider an issue with a single, predetermined approach and “right” or “wrong” answer. In their STEM class, each team of students might choose a different approach for solving the challenge, and several different solutions may work.
- ***Students should use an engineering design process—drawing on science, mathematics, and technology skills and concepts—to solve the challenge.*** However, each subject does not need to be used to the same extent. Some solutions may rely more heavily on science and others on mathematics, but all must require students to use an engineering design process.
- ***The problem should align with grade-level standards for science and mathematics.*** In a busy school day, neither teachers nor students have time for much “extra” curriculum content. The buy in of the designed STE(A)M integrated activity will be much higher if students are able to use skills, they are learning anyway to address the selected challenge.
- ***Students need to have an active role in choosing the challenge.*** Although teachers will need to come up with examples and

## Criteria for approaching & selecting real-world challenges

While approaching and trying to select a real-world challenge, both teachers and students need to consider the following criteria:

- ***The challenge must be real.*** It must involve an authentic challenge grounded in compelling societal, economic, and environmental issues that affect people’s lives and communities. Mythical insects, space aliens, and theoretical life forms are not real-world challenges—at least not yet.
- ***Students must be able to relate to the challenge.*** If students do not care about the challenge, their buy-in will be limited. This needs to be a significant challenge that students care about. It might be a problem in their own life or community. Alternatively, teachers might build a context to help them connect with an





suggestions in order to help students understand the nature of these problems, the final choice should be left to students. Their active involvement paves the way for their engagement and active participation to the learning process.

## INTEGRATED STEM TEACHING STATE OF PLAY

### Desk research

#### Methodology

A search was run in two different databases with scientific journals, namely, ERIC<sup>5</sup> and SCOPUS<sup>6</sup>. According to the definition of integrated STEM given in Section “What is integrated STEM teaching”, we used the keywords «integrated STEM» or «STEM integration» or «STEM-integrated» for the title of journal articles, reviews and commentaries published in English between 2010 and 2019. After deleting a considerable number of articles reporting on stem cell research, and a number of papers not explicitly related to education or integrated STEM, we arrived at a final list of 75 scientific papers, which were all considered for data analysis.

#### Screening and selecting grey literature for the desk research

A search was run for documents published in English between 2010 and 2019 using the following keywords: «STEM»; «integrated»; «framework»; «education»; «recommendations»; «teacher». We also included in our search country names of Europe, United States, and Australia. We considered strategic publications in the form of reports, guidelines, statements, white papers, and frameworks published by institutions like Ministries of Education, partner associations, industry partners, or Advisory Boards. The

following selection criteria were selected for further screening and selecting documents: (1) documents needed to be inclusive in reporting more than single case studies or best practices outlined for one school or teacher; (2) documents needed to either involve more than one STEM discipline or report on integrated STEM practices as defined in Section “What is integrated STEM teaching”; (3) documents needed to report on empirical studies (qualitative, quantitative, mixed methods or meta-analysis); (4) data extracted and reported in documents needed to fully align with research focus and questions. This selection process resulted in a final shortlist of 33 documents, which were all considered for data analysis. The final shortlist included policy documents and educational frameworks of European Ministries of Education, national STEM strategies, initiatives undertaken and documented by schools, documents published by key industry partners.

#### SWOT template

To content analyse these documents, we used a SWOT template, where stakeholders appeared in different columns (primary school teachers; secondary school teachers; Ministries of Education; industry partners). The rows of the template depicted in-group aspects, which either promoted or hindered integrated STEM (Strengths and Weaknesses, respectively), as well as inter-group aspects, which either promoted or hindered integrated STEM (Opportunities and Threats, respectively). Each cell of the SWOT template served as a separate code in a preliminary coding process. We first discussed and elaborated upon classification examples for populating the SWOT template. As new manuscripts were analysed, the content of each cell was reviewed and re-arranged to accommodate new entries and information added in the template. After repeated readings of the corpus and the content of the completed SWOT template, and after deleting cases with

5. <https://eric.ed.gov/>

6. <https://www.scopus.com/home.uri>



overlaps and merging the relevant references, we arrived at the final content of the SWOT template. For assessing reliability in our coding process, we run an inter-rater reliability check between two independent coders at the University of Cyprus, where the inter-rater reliability index amounted to 80%. Unresolved cases were settled through a discussion between coders.

## Desk research findings

### Primary teachers

The main findings from the review about the integrated STEAM approach highlight the following outcomes and evidence related to primary education that we can summarize according to the four categories:

#### Strengths

Strengths for the STEM approach can be identified in the communication within the teacher community and, starting from their acknowledgement that their understanding of integrated STEM is not the only one but by sharing resources and experiences with their colleagues, they can build a common conception. Furthermore, STEM can help teachers to overcome a mechanical approach to the knowledge, since by working on problem-based situations that can involve different disciplines, they can embed engineering design and foster creativity in their classes.

Development and/or revision of teaching resources as well as learning resources for students can be a strength for spreading the Integrated STEM approach, as highlighted by the “National STEM strategies, actions and initiatives” in Czech Republic. In addition, the opportunity for teachers to share their experiences and resources on dedicated websites, through on-line professional

communities or via professional journals can reinforce the efficacy of the previous point.

It is also important to explicitly and roundly share among teachers the concept of the connection among STEM disciplines, then it is more likely for them to collaboratively design a curriculum that encompasses all the four disciplines. The action of negotiation among their different conceptions helps to design a collaborative STEM integrated unit which reflected the conceptions of all parties.

Luppinacci and Happel-Parkins (2017) introduce an ecocritical approach to STEM, opposite to a mechanic way of approaching knowledge building. They cite Bateson and Code, with the purpose to present an ecocritical approach to STEM (social justice and sustainability), which follows a “multidisciplinary/multisensory ecologically-centred education” (Luppinacci & Happed-Parkins, 2017, p. 53). They invite educators to consider “inquiry” as a process “constituted by all the interactions in one’s body and the environment” (p. 58).

Asunda and Mativo (2017) suggest a new way of facilitating STEM teaching for primary students. An integrated problem-based activity, including science, math, engineering, and technology can develop experiences around a theme that is relevant to students’ learning and provide them opportunities to be active learners. Students engage integrated concepts from the four disciplines and “utilize engineering design as a vehicle to solve a problem that has practical consequence” (p. 18).

According to Siew and Ambo’s (2018) studies on primary school students in Malaysia, “the integration of Project-Based Learning and STEM can enhance creativity for scientific solutions” (p. 1018).

English et al. (2017) state that by using an integrated STEM disciplinary approach, and embedding design processes within the problems, it is possible to attempt to target what Lucas and Hanson (2016) refer

to as “engineering habits of mind” (p. 4). These include “problem solving, visualizing, improving, creative problem solving, systems thinking, and adapting” (p. 268).

## Weaknesses

On one hand, a weakness is identified in relation to the lack of a definition of what exactly the STEM Integrated approach is, a definition that is widely shared in the scientific and professional community. However, it is difficult for teachers to determine what integrated STEM education means to them both at a personal and practical level (Guzey et al. 2017, p. 344; p. 348) as long as the ambiguity among practitioners about the definition of STEM persists.

On the other hand, weakness is also related to teacher concerns, mainly about curriculum requirements and assessment but also about the challenge of applying and managing a new approach. That said, some teachers feel a problem-based approach will not work in the classroom due to discipline-specific classes, school organisation and changed pedagogical practice (STEM education for all young Australians, p. 10).

To adopt a STEM perspective, teachers need to adapt their teaching practice, which involves a shift in thinking, and time to learn a different pedagogical approach (STEM education for all young Australians, p14). Teachers may not feel confident with the content, or feel uncomfortable with what is expected of them and it can be overwhelming for them not to know where to begin, especially when attempting to manage the seemingly different outcomes of achieving disciplinary depth and the breadth of boundary-crossing expertise (Samsung - STEM education in Practice, p. 1).

The same source reveals that there are also challenges associated with planning and assessment with some teachers feeling constrained by the discipline specific nature standardised testing (p. 13). They wonder how

STEM methodology influences their ability to meet curriculum and assessment requirements that are usually discipline specific, with no connection between each discipline area as expected in an integrated approach to STEM education (p. 33). Hence issues derive with separating content knowledge and assessments (p. 8).

Furthermore, many teachers have not been given the skills to transfer knowledge in a STEM Classroom (Crossing the Chasm, p. 4). Galadima et al. (2019a) state the need for specific training for pre-service teachers to shift their background (for instance in mathematics) towards a multidisciplinary approach to STEM (p. 1272). Science teachers indeed are not very successful in integrating mathematics in their STEM units, mainly because they might not have subject-matter knowledge.

## Opportunities

One of the main aspects that can promote the design of a framework for integrated STEM education concerns the role played by different parts of the curriculum. In fact, each of them may offer different and specific opportunities to achieve a meaningful integration in those areas.

First, it appears relevant that teachers acknowledge that the point of view typical of their discipline should be negotiated with the other ones, with the aim to design and develop pieces of curriculum integrated and encompassing several conceptions coming from different specialized approaches.

In this perspective, it can be useful to pay attention to the specific contribution potentially given by each discipline of STEM area. For example, according to certain literature, physical science seems to provide a field adequate to connect ideas used in several disciplines, while specific concepts concerning other areas (like earth and life science) appear



to be a little more challenging with regard to integration.

However, it seems necessary to recognize the founding role played by mathematics in producing an integrated view of STEM topics, as well as it is relevant to support the links between maths teachers and their colleagues engaged in others STEM disciplines.

A strategy for integration could consist in using concepts developed in the context of one STEM discipline in another one, in case of recognizing a different meaning of that concepts in different areas, or a different way to use it. Another solution could consist in mixing practices from different STEM disciplines (e.g. experimental procedures combined with engineering design) or selecting an applicative field where competencies in STEM areas could converge.

In any case, the practice of modelling and the use of crosscutting concepts should be the core of an actual integration of STEM teaching, while it should be considered that an integrated teaching does not substitute the necessity to pay attention to specific subjects in the area of STEM disciplines.

Obviously, availability of resources devoted to the design of interdisciplinary educational paths and the accessibility to several programs for professional development offered by several institutions can provide a support to develop integrated educational paths in the STEM areas.

The expansion of the primary curricula also offers opportunities in terms of the adoption of the integrated approach. In Poland for example, the new core curriculum, includes programming teaching from the first grade of primary school, the use of digital technologies and content related to the safe and responsible use of these technologies. The inclusion of these topics offers teachers with more knowledge and practical possibilities in terms

of STEM integration which would have been otherwise impossible.

### Threats

According to literature concerning STEM integration in educational contexts, there are several difficulties in achieving that goal. Mainly, the extension and the quality of didactical resources are not enough.

Designing of effective curricula seems to be a very complex process, due to the low interaction among subjects with different competencies (such as teachers, researchers, educators, engineers), as well as due to the difficulty to produce materials actually understandable to teachers engaged in different areas, with very different expertise.

Another point is the lack of guidance and support to teachers in designing integrated educational paths in STEM areas. In fact, although the existing approaches and the models for STEM integration provide a meaningful conceptualization of integration, they do include clear instructional guidelines for the development of integrated curricular materials. At the same time, although teachers are able to incorporate engineering challenge when creating an integrated STEM unit in the context of an integrated STEM education professional development program, it seems that they need more support to connect science in their units.

Most of the obstacles to develop stable activities devoted to the integration of STEM subjects seem to be due to sustainability of this plan, because of the main role of external agents in promoting an integrated STEM curriculum (STEM education for all young Australians).

Moreover, another difficulty concerns the lack of well-defined assessment methodologies and tools related to integrated paths of learning and teaching in STEM areas. An actual and effective change in teaching approach

requires development of adequate assessment principles and strategies, while the current assessment requirements seem to stand in sharp contrast to integrated STEM education.

Another structural difficulty seems to be the time constraints: time for planning and implement integrated STEM curricula and cost have been suggested as limitations by teachers.

## Secondary teachers

The main findings from the review about the integrated STEAM approach highlight the following outcomes and evidence related to secondary education that we can summarize according to the four categories:

### Strengths

Collaborative pedagogical design promotes integrated STEM education (Kelly and Knowles 2016, p. 4, p. 7). Luppinnacci and Happel-Parkins experienced a planning method with all stakeholders involving all disciplines and sectors connected to STEM Education (social studies, civic life, art, music, physical education, health). “When we begin to think about what constitutes an integrated ecological inquiry, the reconceptualization of curriculum and pedagogy lead us to consider more broadly connections” (p.59). If we take the example of a classroom learning about water, the questions of an ecological inquiry could be: Why does our body contain water? Where does that water, that makes up over 80% of our body, come from? What is in that water? How do different beings interact with, depend on, and use water? etc. (p. 59). Following this way of inquiring leads to a practically minimum separation between social studies and sciences. Moreover, Nadelson et al. (2012) describe their experience related to enhancing collaboration among the school sector, industry, and government. They underline the importance of a STEM vertical curriculum, from pre-primary to higher education, and the value of horizontal collaboration. In fact, they

sustain the importance of networking for the integration of disciplines and the possibility of obtaining more time for doing networking and planning integrated stem curriculum. Teachers should have the opportunity to experience networking. “Perceptions of efficacy for teaching STEM are related to comfort with teaching STEM, pedagogical discontentment with teaching STEM, and inquiry implementation” (p. 79).

The collaboration between teachers in different STEM disciplines is already reported as a positive factor to self-efficacy (STEM Education in Portugal: Education, policies and labour market, p. 5). John and Mentzer (2016) highlight that integrating engineering and science provides opportunities for improving student learning and interest, especially when they are exposed not just to science content but also to scientific enquiry. In fact, scientific inquiry and design-based thinking underlie decision-making processes across Science, Technology, Engineering, and Mathematics. This is the main finding from their study on the engineering lesson titled “Lunar Plant Growth Chamber” developed by ITEA with funding from NASA and provided by NASA Education Resources.

There seems to be a positive feedback loop encouraging peer collaboration when interdisciplinary lessons are implemented in a school. Preble (2015) highlights that biotechnologies in education can offer many opportunities for STEM integration: the focus is not only on technology and engineering, but other subjects can be brought in to add depth to this topic such as science, English, and history. “Biological and agricultural engineering has existed for millennia. Current modifications at the genetic level can trace their origins to macro practices. Students can be introduced to this topic by developing an understanding of the practice of grafting apple trees. It is important for students to understand current



agricultural practices and their implications” (p. 24).

Schedules with common planning time allow teachers to be innovative and implement an integrated STEM model. Dare et al. (2018) underline in their study that it could be useful to describe situations in which teachers experience their implementation. For instance, teachers affirm that integrating STEM requires additional time. In addition, the authors reported that “one of the major challenges for these teachers was maintaining a balance between teaching the science content that they were required to teach and making sure the engineering design challenge was (1) engaging students and (2) something that their students could reasonably do” (p. 17).

### Weaknesses

A wide range of challenges for connecting STEM disciplines have been identified. First of all, inadequate knowledge concerning disciplines, pedagogical content knowledge and inadequate experience of peer collaboration came out from a certain number of studies (Kelly and Knowles 2016, summary; English and King, 2015; Radloff and Guzey, 2016, Chalmers et al., 2017, cited in Huri and Karpudewan, 2019, page 495; Brown and Bogiages 2019, page 116; Lederman & Lederman, 2013; Ball, Thames & Phelps, 2008 and Berlin & White, 2010 and Frykholm & Glasson, 2005 cited in Brown and Bogiages 2019, p. 112; 20, p.190; Angwal et al. 2019; Banilower, 2013; cited in 34, p. 496; 34, p. 506; 64, p.8-9).

Creating connections between STEM disciplines is challenging, since it requires time investment in cross-disciplinary and collaborative pedagogical design (Thibaut et al. 2017, page 9; Stohlman, Moore & Roehrig, 2012 cited in Brown and Bogiages 2019, page 126; Dare et al. 2018, page 17;). Lack of the pedagogical content knowledge needed to integrate the appropriate levels of mathematics and science instructional content is the number one

challenge for engineering integration (Kelley and Wicklein 2009, p. 45). Engineering was the content area with the lowest rating of both teacher perceived importance and confidence for integration (Smith et al. 2015, p. 191). Lack of knowledge and skills that are necessary to teach integrated STEM content through problem and project-based learning and engineering design has been shown. Teachers’ low self-efficacy due to lack of content knowledge (e.g., Leader-Jansen & Rankin-Ericksons 2013; Swackhamer et al., 2009; Woolfolk Hoy & Spero, 2005), increase their fear to teach engineering design in their classes (Cunningham, p. 496). Many educators fail to move beyond merely the use of educational technology to enhance STEM learning experiences (Cavanagh 2008). Female teachers reported lower perceived importance of and confidence in integrating technology concepts (Smith et al. 2015, p. 192). Teachers do not have sufficient understanding of the T in STEM and the interactions between technology and other disciplines (El-Deghaidy and Mansour 2015, p. 2)

Integrated STEM education necessitates a break from traditional instruction and planning. More years of teaching are linked with lower attitudes toward teaching integrated STEM (Thibaut et al. 2018, p. 645). Teachers’ resistance or lack of motivation to change their beliefs and practice poses a challenge to integrated STEM education (Ashgar et al., 2012, p. 2). Teachers are also reluctant to ask for help. Finally, using a community of practice approach to integrated STEM can be challenging for teachers as they need to continually network with experts and allow members of the community of practice into their classroom (Kelly and Knowles 2016, p. 7).

### Opportunities

Participation in professional development focused on integrated STEM is positively correlated with teachers’ attitudes and competence in designing and implementing integrated STEM education (Thibaut et al. 2018,

p. 644; Thibaut et al. 2019, p. 1000; Brown and Bogiages 2019, p. 115). For teachers to learn how to teach through integration, they need to experience STEM integration as a learner. Matching the disciplinary focus of the first integrated STEM task that teachers experience with that of the teachers' background knowledge supports an engager disposition (Brown and Bogiages 2019, p. 125). In-service professional development programs for integrated STEM education resulted in an increase in teachers' comfort to teach STEM, STEM knowledge, peer collaboration (Nadelson et al. 2012, p. 79), and beliefs about benefits of integrated STEM education. Both teachers and administrators acknowledge the need for new in-service professional development programs for integrated STEM education. Participatory design processes reported for integrated STEM education in pedagogical design initiatives involving multiple stakeholders, directing the curriculum towards the recognition of "the difference between an anthropocentric understanding versus an ecological understanding" (Nadelson et al. 2012, p. 79).

Rubrics should be available for participatory design in integrated STEM education (Hussin et al. 2019, p. 207). Galadima et al. presented a framework for integrated STEM education for pre-service teachers (2019b, p. 1273). Both teachers and administrators acknowledge the need for new pre-service education programs for integrated STEM education.

When it comes to students, Sarican, G. and Akgunduz, D. (2018) state that with project-based education integrated with math, engineering, technology, and science courses, their desire to learn and their learning levels could be higher at lower secondary education level.

At a country level, the Finnish national curriculum emphasizes the use of integrated teaching in general. The completely revised curriculum for secondary education will be introduced in 2021 and is expected to provide

more guidance on how the implementation of integrated teaching will be materialized.

### Threats

Several authors underline concerns and misconceptions to be considered before planning an integrated STEAM curriculum.

Among the main concerns, El-Deghaidy et al. (2017) problematize the use of multidisciplinary and interdisciplinary learning when talking about STEM. According to them "multidisciplinary learning refers to 'additive knowledge' where various disciplines are combined together yet each discipline is independent and separate to the others" (p. 2461). "Interdisciplinary learning can be perceived as a radical reconstruction of the whole learning process [...] Interdisciplinary learning impacts life-long learning, habits, academic skills, personal growth" (p. 2461).

Since integrated STEAM education requires numerous materials and resources (Stohlmann et al., 2012) creating a supportive school culture and environment is costly and time-consuming (Hardy, 2001, Nadelson and Seifert, 2017; cited in Thibaut et al. 2017, p. 2). The traditional school culture regarding pedagogical approaches is a crucial barrier for implementing an integrated STEM lesson. School organization (i.e., schedule of classes) does not allow teachers to find common blocks of time for collaboration for the development and implementation of integrated lessons.

Moreover, pre-service teacher education rarely offers integration experiences (Roebuck and Warden 1998). Even if pre-service teacher training courses prepare university students to design integrated STEM lessons, not all of them have experience of how interdisciplinary work looks like in real professional fields. When STEM pre-service teachers do not have a thorough understanding of each one of the



STEM disciplines, then they are not capable of designing an integrated STEM lesson plan.

As far as professional development, Roehrig et al.'s (2012) study showed that integrated STEM at secondary level can be successful through different organization models (team-teaching; co-teaching; individual teaching), provided that teachers receive proper continuous professional development in this field.

## Ministries of Education

### Strengths

While looking into the Ministries of Education (MoEs) and how their priorities and reforms include STEM Integrated Learning, our search took us outside Europe and more specifically to the US. There, a number of recent reforms such as the Next Generations Science Standards (NGSS) (NGSS Lead State 2013) and Common Core State Standards for Mathematics (CCSSM) (National Governors Association Center for Best Practices & Council of Chief State School Officers 2010) advocate for purposefully integrating STEM by providing deeper connections among the STEM domains (Kelly and Knowles 2016, p. 2).

Back to Europe, Israel has a dedicated STEM strategy, designed and rolled out by the MoE in 2010, to strengthen science and technology studies. Moreover, two Royal Decrees published in Belgium in 2014 and 2015 aimed to incorporate institutional reforms into primary and secondary education, where the development of STEM skills must be promoted by means of integrated learning. This implies that teaching of STEM competences must be approached from all areas of knowledge.

### Weaknesses

When it comes to the weaknesses, STEM disciplines are represented unequally throughout the different curricula. Very often,

STEM initiatives involve mathematics and science teachers only, while technology and engineering teachers are left outside of the equation (Moye, Dugger, and Starkweathe, 2012). At the same time, in primary education, most of the STEM teaching and learning is focused on science and mathematics with very little input from technology and engineering (Susilo et al. 2016, p. 48).

In secondary education, the segregation of disciplines is another major issue. The current curricula do not foster STEM integration and thus must be redesigned and reorganised. Secondary education includes a kind of silo of STEM subjects within a rigid structure with departmental agendas, requirements, content standards, and end of year examinations, which constrain integration (Kelly and Knowles 2016, p. 9). The complexity and rigidity of these structures blocks current connections or fails to identify them when available (NAE and NRC 2009; cited in Kelly and Knowles 2016, p. 3).

At the moment of writing and at a country level, four countries (Greece, Turkey, Slovenia, and Slovakia) do not consider STEM education as a particular current priority on a national level. Consequently, the lack of STEM education strategy weakens the possibility for STEM integrated teaching to enter schools.

### Opportunities

Engineering-based projects, engineering-based design and Robotics can be used to promote integrated STEM Education. The reason for that is that these types of projects and activities are based on PBL and can easily provide integration opportunities. Another important area, with various sub-categories of topics that can be examined in class, is Climate change. A wide variety of options to develop successful examples of integrated STEM teaching materials can be produced under the umbrella of this extremely relevant topic for society, economy, and education. Those examples, depending on the priorities by Ministries of



Education, can range from renewable energy, tackling ocean pollution, recycling, and biodiversity among others. In addition, there are endless possibilities to combine subjects that relate to citizen science, history, and even foreign languages and policy making in order to enhance the interdisciplinarity of those materials, and additionally produce remarkable learning products to support the research that took place and materials produced by the students.

### Threats

Moving on to difficulties, and while designing activities and pedagogical scenarios for integrated STEM education, the knowledge of some higher-level mathematics, such as solids or revolution, is not easy to be included in STEM integrated tasks. In addition, teachers believe that some science subjects, specifically physics' topics such as energy, force, etc., are more suitable for STEM integration, whereas chemistry and biology for example are not (Kelly and Knowles 2016, p. 36). To achieve STEM integration, it is also important to focus on learning goals and standards in the individual STEM subjects, so as not to inadvertently undermine student learning in those subjects (Pearson, 2017; cited in Thibaut et al. 2017, p. 6). Although the benefits of integration are undeniable, several papers (e.g., Guzey et al., 2016; Pearson, 2017) warn that integration should remain meaningful and purposeful and that more integration is not necessarily better (Thibaut et al. 2017, p. 6). In this direction, Texas Instruments provided the example of the German state of Sachsen where hands on experiments need to be performed as part of the high-stake exams (Abitur).

An additional risk is related to assessment. When it comes to STEM integration, there is a lack of assessment tools tailored to it. With final exams (or annual exams) being used as the main assessment tool, teachers are discouraged to implement integrated STEM lessons. The preparation of students for standardised

exams, does not allow teachers to devote time to integrated STEM Education. Requiring from students to assess their understanding of each STEM subject is essential, and for this reason emphasis should be put on the learning products they will deliver after each activity in the context of the various STEM subjects. Those learning products may vary in nature and range from spreadsheets they worked on in pairs or engineering projects they worked on as groups. Nevertheless, learning products will allow for hands-on practice of what students have been taught and their quality will indicate their level of understanding, knowledge acquired, and research they did.

### Industries

The main findings from the review about the integrated STEAM approach highlight the following outcomes and evidence related to industries that we can summarize according to the four categories:

### Strengths

Despite the fact that, in many cases, STEM education is not even on the roadmaps of educational institutions (Crossing the Chasm, p.4), industry bodies and professional organisations have highlighted the importance of the STEM agenda, and recognised the role education plays in STEM futures (STEM education for all young Australians, p. 17). Therefore, industries are starting to fund learning programmes in STEM, since it is believed to contribute developing knowledge and skills in the workforce which are needed for employment.

There is steady funding in the US for STEM programs, as well as many private contributions to STEM classrooms. Companies such as Oracle are well known to be huge financial supporters



of STEM education, as it creates workplace-ready graduates for their employment.

At a European level, Volkswagen Foundation is promoting STEM, in particular VET (Vocational Education and Training) in Slovakia. The focus is on the introduction of a dual education system with more emphasis on praxis. Their programme is oriented for three education programmes: mechatronics, industry mechanics, and tools mechanics.

Other examples of privately funded initiatives that actively support STEM education and teachers by producing learning materials, and also providing training opportunities for teachers include Texas Instruments<sup>7</sup>. Texas Instruments has produced learning materials that address the educational needs of students in all classes of the K-12 education placing particular attention in the areas of mathematics, science, programming, and engineering. In addition, opportunities for the professional development of teachers like workshops and webinars are available. IBM has been supporting STEM and digital education by supporting educational programs both in the United States but also internationally, focusing on technical and vocational education. Lastly, the Amgen Teach program<sup>8</sup> supported by the Amgen Foundation, has supported over 4,000 science teachers across Europe since its launch in 2014. Life science teachers in secondary education have the opportunity to receive training on how to apply inquiry-based science education in their classroom.

This contributes to increase the perception that STEM graduation offers better guarantees of employment (STEM education in Portugal: Education, policies and labour market, p. 17), therefore some educational institutions are starting to activate partnerships with industries, among other external organisations such as universities and associations, to provide high quality STEM experiences for students.

Through partnerships, students can access mentors and resources otherwise unavailable.

### Weaknesses

In many countries, information about STEM careers is lacking, which means students are misinformed or do not know about STEM careers. In fact, there can be issues around the programs leader's ability to implement a STEM program. Limitations may include lack of STEM knowledge, confidence, and self-efficacy in teaching STEM for those who were implementing the programs. Lack of STEM knowledge can make it difficult for the program leader to perceive the difficulty of the activity, and tailor activities to the age of students. As programs such as these are usually provided by external providers, access to such programs for disadvantaged students may be limited. This may be due to issues around the proximity of a school to providers, and the cost of such programs. There is not yet enough cooperation between science and business and science-based innovations. These issues created the basis to define national progress strategies such as "Lithuania 2030" and the "State Education Strategy" 2013-2020.

### Opportunities

One common element that creates opportunities of STEM activities led by industry stakeholders is the increasing number of professionals in STEM fields working together with students creating mentoring relationships where the mentors have multiple roles like tutor, educator, role model or simply as representative who work in STEM area. The involvement of STEM professionals in formal or informal learning activities seems to be an effective tool to increase the engagement of students with the STEM fields (Defining a Research Agenda for STEM Corps: Working White Paper, p.9). It is also very important

7. (Texas Instruments - Education engagement, 2020)

8. <http://www.amgenteach.eu/about>

the opportunity to foster together with stakeholders a strong pipeline of educators who are effective at teaching STEM subjects and are skilled at using technology which goes perfectly along with the need to integrate technology into STEM teaching and learning.

Innovative new ideas and creative solutions often emerge at the interface between disciplines and involve different societal actors. The development of innovative new school models and school networks that partner with museums, research centres and STEM-based industry partners are a way to make the subjects more appealing, engaging, and accessible to a wider range of students.

For this reason, public and private sector stakeholders should work together to develop or enhance existing investments in STEM education to foster STEM skills. The beneficial role of 'cross-border exchange of ideas and novel practices' could be considered as a tool to build alliances with industrial, corporate and political bodies. Important for the success of these actions is how the programs fit with curriculum standards and sustainability of the pedagogical approaches. A successful example of all the above is the STEM Alliance initiative.<sup>9</sup> STEM Alliance aims to bring industry experts closer to teachers and students promoting first and foremost the attractiveness and importance of STEM studies and STEM jobs in schools. This is achieved with the opportunity to generate dialogue between schools and industry, including training opportunities for teachers that STEM Alliance actively supports. Students cannot be expected to choose STEM-related study paths and careers solely based on personal preference or inclination towards STEM subjects that are traditionally seen as difficult. Therefore, representation and contextualization matter a lot.

Industry experts in collaboration with teachers can provide an insight of what they do and the reasons it is relevant to the world. In addition, teachers and students through this initiative

and the insight to so many and diverse STEM job profiles, have the opportunity to understand in a more well-rounded, coherent way how the knowledge they acquire at school can be applied in the various fields of industry. Furthermore, by supporting and promoting educational initiatives at school level, industry will benefit from this type of investment and involvement in the long-term. When it comes particularly to Europe, ensuring that students who will graduate in the near future are highly skilled and possess the competences to excel in a knowledge-based, technology-enhanced workforce is mandatory. By exposing students to STEM subjects and careers, they are also exposed to all sorts of processes from product development to demand and innovation; this additionally results in students exercising their entrepreneurial spirit which is crucial in industry as well. Ultimately, the promotion and support of the collaboration between industry and schools across all Member states in Europe, directly relates to the economic prosperity of the continent and its chances to compete globally.

### Threats

Technological development is necessary for continued economic development. A future shortage of a labour force skilled in STEM disciplines is seen as an obstacle to economic growth. This foreseen workforce shortage is due to two demographic facts:

- relatively fewer young people will move through the education system towards labour markets, and lower proportions of these young people are being attracted to studies in the STEM disciplines.
- relatively high numbers of current labour market participants are approaching retirement age.

Often the educational programs in STEM are taking place in locations close to the provider, for

9. <http://www.stemalliance.eu/home>



example an industry partner. This is potentially an issue for disadvantaged regions as they are not always located near providers. In addition, many of these programs often focus on specific subject areas of the provider rather than taking a formal and integrated approach.

On one hand the STEM activities provided by industry often are not connected with the formal activities in schools and/or the curriculum, on the other hand the STEM school activities often lack real-world project-based examples and authenticity.

If the STEM activities provided by the stakeholder are not systemically connected to the curriculum, they will be far from being adopted by most schools and teachers. Another issue is that creativity and innovation are in the spotlight to formal education but it's still difficult to measure the impact of these programmes and their overall efficiency. The future task should be to establish a standard to evaluate these processes, so that the positive outcomes of these experimental or innovative programmes could be integrated in a structured national programme more connected to STEM curricula (Consultant-Report-Western-Europe, p. 11-13).

### Stakeholders' Questionnaire (focus on teachers)

A stakeholder questionnaire was developed based on the desk research conducted. As mentioned, four main stakeholders were present in the columns of the SWOT table, namely primary school teachers, secondary school teachers, Ministries of Education, and industry partners. The rows of the template depicted in-group aspects, which either promoted or hindered integrated STEM (Strengths and Weaknesses, respectively), as well as inter-group aspects, which either promoted or hindered integrated STEM (Opportunities and Threats, respectively). Each

cell of the SWOT template served as a separate code in a preliminary coding process.

After repeated readings of the corpus and the content of the completed SWOT template, and after deleting cases with overlaps and merging the relevant references, the final content of the SWOT template was used as the basis for the development of the stakeholders' questionnaire. The constructs and items developed in the questionnaire were formulated in such a way to confirm the main findings of the SWOT analysis and serve as the starting point for discussion about the development of the integrated STEM framework. Specifically, the aim of the questionnaire was to collect information on stakeholders' views regarding STEM integrated teaching, available resources, and the barriers to its implementation.

The stakeholders' questionnaire consists of 47 items in a five-point Likert scale (completely disagree; disagree; neutral; agree; completely agree). The items are organized around 11 constructs– *Concept; Responsive instruction; Resources available; Pedagogical design; Funding; Professional development; Pre-service teacher education; Organizing principle; Main barriers to integrated STEM education; Change and Careers*. Each stakeholder group has been assigned to response to specific constructs, as shown in Table 1: Distribution of questionnaire's constructs per stakeholder group. The items in each construct are provided in the Annex.

Table 1: Distribution of questionnaire's constructs per stakeholder group

	No of items	TEACHERS	MINISTRIES OF EDUCATION	INDUSTRY
<b>Concept</b>	5	X		
<b>Responsive instruction</b>	4	X		
<b>Resources available</b>	5	X	X	
<b>Pedagogical design</b>	4	X	X	
<b>Funding</b>	4	X	X	X
<b>Professional development</b>	4	X	X	
<b>Pre-service teacher education</b>	4		X	
<b>Organizing principle</b>	4	X	X	X
<b>Main barriers to integrated STEM education</b>	5	X	X	
<b>Change</b>	4	X	X	X
<b>Careers</b>	4			X
<b>Total</b>	<b>47</b>	<b>39</b>	<b>34</b>	<b>16</b>

The five items under the construct *Concept* measure teacher conceptual understanding for integrated STEM education (e.g., «I have a clear understanding of what integrated STEM education is») and whether teachers know which approaches need to be considered and how these may be employed in relation to integrated STEM teaching practices (e.g., «I can employ teaching approaches that foster integrated STEM education»). Moving from concept to practice, the construct *Responsive Instruction* aims to measure teachers' competencies to design (e.g., «I feel competent to design an integrated STEM lesson plan») and implement an integrated STEM lesson plan (e.g., «I feel competent to orchestrate an integrated STEM lesson»). The next construct, namely *Resources Available*, measures teachers' views about the amount and quality of the available resources and material for integrated STEM education (e.g., «There are enough resources and material available for integrated STEM education»; «The resources and material available for integrated STEM education are interesting for students»). The next group of items address the *Pedagogical Design* by measuring teachers' views about collaboration, either between teachers (e.g., «Many teachers are willing to

collaborate with their colleagues in designing lesson plans for integrated STEM education»), or between teachers and other stakeholders (e.g., «Collaboration between stakeholders can deliver more interesting resources and material for integrated STEM education than are currently available»). The items that constitute the construct *Funding* aim to collect insight into teachers' awareness about funding opportunities for integrated STEM education, at the national or the European level (e.g., «There are many opportunities to support integrated STEM education by funding at the national level»). The next construct addresses *Professional Development* and aims to measure teachers' perceptions about the proficiency of professional development programmes in terms of promoting integrated STEM education (e.g., «Professional development programmes focus much more on each one of the STEM disciplines than on their integration»). The construct *Organizing Principle* contains items referring to the approach and disciplines that teachers consider as the guiding principle for integrated STEM education (e.g., «Engineering design education can be used as an organizing principle in integrated STEM education»). The next construct concerns the *Main Barriers to Integrated STEM Education*,



aiming to measure teachers' views about the effect of the school environment and everyday practice, teacher skills, curriculum requirements, and assessment methodologies (e.g., «Current curriculum requirements do not favour integrated STEM education»). The final construct of the questionnaire targeting teachers, called *Change*, focuses on teachers' views about the level of change that is needed so that integrated STEM education can become a priority (e.g., «A national strategy for integrated STEM education is missing»).

## Questionnaire Data Analyses

### Sample characteristics

A total of 71 respondents completed the online questionnaire. We excluded from data analysis respondents who worked in a country outside Europe (4 respondents), and we also deleted another 2 respondents who represented industry partners. This later deletion was necessary since we had only these 2 respondents from the stakeholder group of industry partners, which was not enough for comparisons between stakeholder groups. The final sample included 65 respondents: 9 represented Ministries of Education, 12 were teachers in primary education, while 44 were teachers in secondary education. Teachers had, overall, a median of 4 years of teaching experience (max = 6 years; min = 1 year) and came from 21 different countries. Before completing the questionnaire, all respondents provided their consent to the Data Protection Disclaimer Information on data collection and processing.

### Validity and Reliability Analyses

Validity and reliability analyses were conducted for all scales, apart from «Pre-service teacher education» and «Careers», for which we did not receive enough responses to run these analyses. With regard to validity analysis, we conducted a factor analysis (extraction: Principal component; rotation: Varimax; Kaiser-Meyer-Olkin Measure of Sampling

Adequacy = 0.87; Chi-Square for the Bartlett's Test of Sphericity = 6687.22,  $p < 0.001$ ), which revealed that all items loaded on two factors, together explained 91.69% of total variance in the data. All items of the scales «Resources available», «Pedagogical design», «Funding», «Professional development», «Organizing principle», «Main barriers to integrated STEM education», and «Change» loaded on factor 1, while all items of the scales «Concept» and «Responsive instruction» loaded on factor 2. This allocation of items on factors revealed that items maintained their scale-reference, when the responses of the sample were accounted for, and therefore, our instrument was valid. Further, factor 2 («Concept»; «Responsive instruction») seems to reflect the basics of teacher preparation for integrated STEM, whereas the rest of the scales allocated on factor 1 address institutional support needed and stakeholder preparedness to promote integrated STEM.

With regard to reliability analysis, most scales revealed Cronbach's alpha indices over 0.70 (Cronbach's alpha for: «Concept» = 0.80; «Responsive instruction» = 0.84; «Resources available» = 0.89; «Professional development» = 0.82; «Organizing principle» = 0.82; «Main barriers to integrated STEM education» = 0.86), reflecting satisfactory reliability, while three scales revealed marginal reliability (Cronbach's alpha for: «Pedagogical design» = 0.61; «Funding» = 0.66; «Change» = 0.56).

### Responses of Stakeholder Groups to Questionnaire Items

Non-parametric statistical tests (Kruskal-Wallis and Mann-Whitney tests) revealed no statistically significant differences between stakeholder groups across all scales, after the implementation of the Bonferroni correction for multiple comparisons. In addition, there were no statistically significant trends related to years of teaching experience. However, there were some major trends in data. Stakeholder groups presented a consistent pattern across all scales, with teachers in primary education

having the relatively highest average values for all items, followed by teachers in secondary education, and then, representatives of Ministries of Education (see Tables 1-9 in the Appendix).

Starting with «Concept» (see Table 2: Average responses of stakeholder group for the scale «Concept») and «Responsive instruction» (see Table 3), primary school teachers reported a better comprehension of integrated STEM («Concept») and they were, according to their

self-reports, much more competent in designing and implementing integrated STEM lessons («Responsive instruction») as compared to secondary school teachers. Since these two scales were allocated on factor 2, our findings indicate that primary school teachers appeared more prepared than secondary school teachers for moving towards the direction of integrated STEM. We need to highlight that these two scales were not distributed to representatives of Ministries of Education.

Table 2: Average responses of stakeholder group for the scale «Concept»

	Ministries of Education (n=9)	Teachers in primary education (n=12)	Teachers in secondary education (n=44)	Total sample (n=65)
I have a clear understanding of what integrated STEM education is	-	3.92	3.14	2.85
I have heard colleagues talking about integrated STEM education	-	3.25	2.82	2.51
I have talked with colleagues about integrated STEM education	-	3.92	3.09	2.82
I know how to develop an engineering design task for my students	-	3.33	2.75	2.48
I can employ teaching approaches that foster integrated STEM education	-	3.67	2.91	2.65

Note: Items for the scale “Concept” were not included in the instrument for Ministries of Education; values present average responses of stakeholder groups along a 5-point Likert scale (min = 1; max = 5).

Table 3: Average responses of stakeholder group for the scale «Responsive instruction»

	Ministries of Education (n=9)	Teachers in primary education (n=12)	Teachers in secondary education (n=44)	Total sample (n=65)
I feel competent to design an integrated STEM lesson plan	-	3.67	2.89	2.63
It is easier for me to design an integrated STEM lesson plan based on a given example	-	3.58	2.98	2.68
I feel competent to orchestrate an integrated STEM lesson	-	3.58	2.80	2.55
I can offer support to my students when they enact an integrated STEM learning task	-	3.75	2.93	2.68

Note: Items for the scale “Responsive instruction” were not included in the instrument for Ministries of Education; values present average responses of stakeholder groups along a 5-point Likert scale (min = 1; max = 5).



An analogous trend was revealed for scales which loaded on factor 1, and which referred to additional institutional support needed and stakeholder preparedness to promote integrated STEM. Primary school teachers were more optimistic on the availability of quality educational resources («Resources available» shown in Table 4), teacher and stakeholder

collaboration for facilitating pedagogical design for integrated STEM («Pedagogical design» in Table 5), availability of funding opportunities («Funding», see Table 6) and professional development programmes for integrated STEM («Professional development», see Table 7).

Table 4: Average responses of stakeholder group for the scale «Resources available»

	Ministries of Education (n=9)	Teachers in primary education (n=12)	Teachers in secondary education (n=44)	Total sample (n=65)
There are enough resources and material available for integrated STEM education	1.22	3.25	2.57	2.51
The resources and material available for integrated STEM education are useful	1.44	3.25	2.84	2.72
The resources and material available for integrated STEM education can be easily implemented in everyday school practice	1.22	3.00	2.59	2.48
The resources and material available for integrated STEM education fit with the national curriculum	1.56	2.92	2.39	2.37
The resources and material available for integrated STEM education are interesting for students	1.78	3.33	2.95	2.86

Note: Values present average responses of stakeholder groups along a 5-point Likert scale (min = 1; max = 5).

Table 5: Average responses of stakeholder group for the scale «Pedagogical design»

	Ministries of Education (n=9)	Teachers in primary education (n=12)	Teachers in secondary education (n=44)	Total sample (n=65)
Many teachers are willing to collaborate with their colleagues in designing lesson plans for integrated STEM education	1.44	3.08	2.39	2.38
Collaboration between teachers can deliver more interesting resources and material for integrated STEM education than are currently available	1.89	3.83	2.91	2.94
Many teachers are willing to collaborate with stakeholders in designing lesson plans for integrated STEM education	1.56	3.25	2.34	2.40
Collaboration between stakeholders can deliver more interesting resources and material for integrated STEM education than are currently available	1.89	3.67	2.93	2.92

Note: Values present average responses of stakeholder groups along a 5-point Likert scale (min = 1; max = 5).





Table 6: Average responses of stakeholder group for the scale «Funding»

	Ministries of Education (n=9)	Teachers in primary education (n=12)	Teachers in secondary education (n=44)	Total sample (n=65)
Industry partners should allocate more funding to integrated STEM education	1.89	3.67	2.95	2.94
Ministries of Education in Europe should allocate more funding to integrated STEM education	1.78	3.83	3.00	2.98
There are many opportunities to support integrated STEM education by funding at the national level	1.11	2.50	2.43	2.26
There are many opportunities to support integrated STEM education by funding at the European level	1.56	3.33	2.80	2.72

Note: Values present average responses of stakeholder groups along a 5-point Likert scale (min = 1; max = 5).

Table 7: Average responses of stakeholder group for the scale «Professional development»

	Ministries of Education (n=9)	Teachers in primary education (n=12)	Teachers in secondary education (n=44)	Total sample (n=65)
Professional development programmes offer enough opportunities for engaging teachers in integrated STEM education	1.22	3.33	2.45	2.45
Professional development programmes promote collaboration among teachers for designing lesson plans in integrated STEM education	1.33	3.50	2.52	2.54
Professional development programmes promote collaboration among stakeholders for designing lesson plans in integrated STEM education	1.33	3.25	2.30	2.34
Professional development programmes focus much more on each one of the STEM disciplines than on their integration	2.11	3.00	2.77	2.72

Note: Values present average responses of stakeholder groups along a 5-point Likert scale (min = 1; max = 5).



A further indication of the optimism of primary school teachers is that they believed that several options could serve as organizing principles of integrated STEM («Organizing principle» in Table 8).

This optimism was accompanied by endorsement of all multifarious adaptation and change needed for fostering integrated STEM (See Table 9: «Main barriers to integrated STEM education», and Table 10, «Change»).

Table 8: Average responses of stakeholder group for the scale «Organizing principle»

	Ministries of Education (n=9)	Teachers in primary education (n=12)	Teachers in secondary education (n=44)	Total sample (n=65)
Engineering design education can be used as an organizing principle in integrated STEM education	1.89	3.42	2.86	2.83
Project-based learning can be used as an organizing principle in integrated STEM education	2.11	3.75	3.09	3.08
Robotics can be used as an organizing principle in integrated STEM education	1.67	3.75	2.91	2.89
Each STEM discipline can serve as an organizing principle for integrated STEM education	1.67	3.67	2.93	2.89

Note: Values present average responses of stakeholder groups along a 5-point Likert scale (min = 1; max = 5).

Table 9: Average responses of stakeholder group for the scale «Main barriers to integrated STEM education»

	Ministries of Education (n=9)	Teachers in primary education (n=12)	Teachers in secondary education (n=44)	Total sample (n=65)
Average school culture and environment does not favour integrated STEM education	1.89	3.25	2.68	2.68
Everyday school practice does not favour integrated STEM education	1.89	3.17	2.64	2.63
Average teacher skills do not favour integrated STEM education	2.00	3.00	2.68	2.65
Current curriculum requirements do not favour integrated STEM education	1.67	3.50	2.80	2.77
Current assessment methodologies for students do not favour integrated STEM education	1.89	3.50	2.86	2.85

Note: Values present average responses of stakeholder groups along a 5-point Likert scale (min = 1; max = 5).

Table 10: Average responses of stakeholder group for the scale «Change»

	Ministries of Education (n=9)	Teachers in primary education (n=12)	Teachers in secondary education (n=44)	Total sample (n=65)
All stakeholders agree that reform is needed to foster integrated STEM education	1.89	3.67	2.75	2.80
Drastic institutional change is needed for integrated STEM education	2.00	3.58	3.02	2.98
A national strategy for integrated STEM education is missing	1.89	3.83	2.95	2.97
Integrated STEM education should be a priority for Europe	2.00	3.83	3.18	3.14

Note: Values present average responses of stakeholder groups along a 5-point Likert scale (min = 1; max = 5).

## Main Discussions Points

Data analysis showed that the questionnaire includes six scales of satisfactory reliability («Concept»; «Responsive instruction»; «Resources available»; «Professional development»; «Organizing principle»; «Main barriers to integrated STEM education») and another three of marginal reliability («Pedagogical design»; «Funding»; «Change»). We need to consider omitting these three scales from the final form of the instrument. All scales comprised a valid instrument, altogether, to be used for assessing stakeholder positions.

With regard to the basic aspects of teacher preparation for implementing integrated STEM (scales «Concept» and «Responsive instruction», which loaded on factor 2), primary school teachers appeared more prepared than secondary school teachers to take up integrated STEM. It can be that the primary school curriculum may be much more compatible with integrated STEM than the secondary school curriculum, which has the characteristic of a compartmentalization of STEM domains, with many implications for learning and instruction, everyday school practice, and teacher attitudes. In some cases, this separation has gradually cultivated an analogous positioning of teachers' trade unions

and may have a substantial effect on teachers' willingness to implement integrated STEM.

A possible implication and limitation of our approach may have been the disproportional frequency of stakeholder groups in our sample. Larger numbers of respondents, distributed more evenly across stakeholder groups, may have substantiated our findings better. However, we need to underline that the current sample represented 21 different countries in Europe, providing a notable geographical coverage. Any future use of the questionnaire will add to the robustness of the findings outlined in this report.



## STE(A)M INTEGRATED TEACHING EXAMPLES

To provide an idea of STE(A)M Integrated teaching, we are providing three examples. At the end of 2020, STE(A)M IT will offer fully developed Integrated STEM Teaching Learning Scenarios.

### Example of using design as a context for integration

*Source: (STEM Integration in K-12 Education: Status, Prospects, and an Agenda for Research (2014))*

In a study with 12-year-old students, the activity of designing vessels that float was used to make learning from experimentation more relevant to the students (Schauble et al. 1995). After being given a design brief, students individually constructed vessels and added weight until the vessel sank. They then graphed their vessel with others that had similar carrying capacities. This was followed by further individual work in which students drew designs from various views and reflected on their previous design in a journal. Working in teams, students negotiated their designs by experimenting with various aspects of them. These efforts were supplemented by teacher and whole-class discussions of concepts such as buoyancy and relative density. By synthesizing the data from the experimentation, students could go on to plan their final design.

During this activity across several classrooms, a number of instructional challenges emerged. Although reflection is critical to learning, it was difficult to balance reflection activities with time spent on the more dynamic portions of the design process. It was also difficult to keep students focused on the design rather than on diversions while still valuing their background knowledge. And it was challenging to ensure that students not only remained focused on their goal of making the best vessel but also

understood how various aspects of design could lead to improvements.

Analysis of interviews with the students before and after the activity revealed that they learned science through design and showed an improved understanding of experimentation. It also revealed that, from an instructional perspective, it was important to change only one variable at a time. This was true even when variables that would not affect the outcome of an experiment were altered. Instances in which teachers substituted or altered one irrelevant variable (such as using different types of weights that look different but are the same weight) led to confusion for the students, who were still developing an understanding of experimental procedure. Furthermore, teachers rarely discussed patterns in data, assuming that they were obvious to the students; this was demonstrated not to be the case. Finally, students were not spontaneously aware of the value of examining the unsuccessful vessels for attributes to be excluded; this useful skill can be nurtured by explicitly drawing attention to it (Schauble et al. 1995).

This example highlights the importance of framing and instructional support in design activity for integrated STEM learning.

### Example of combining literature, mathematics, and engineering

*Source: European Schoolnet*

Math problems are full of words and focusing on literacy can help improve a student's ability to make sense of word problems. It can also help to remove the fear of mathematics by connecting it to the real world. For example, students can tie their learning of numbers by reading *Alice in Wonderland* and trying to identify and make sense all the different mathematical concepts and engineering clues and challenges that pop up throughout the story. Reading the book in a mathematics class improves literacy and brings mathematical

skills to life by showing a real-life application for a skill learned in class.

Using the same book and the sources of inspiration, an engineering problem can also be posed to students i.e. how can we help Alice get out of the rabbit hole?

And using fiction in mathematics, students can practice invaluable literacy skills while also seeing the practical applications of math, which can help remove math fatigue.

### Example of addressing Climate Change in integrated STEM learning

Source: *European Schoolnet*

Climate change is an extremely relevant and multifaceted theme that can be approached and addressed by teachers in both Primary and Secondary education equally successfully. As a theme it touches upon a wide selection of subjects, both STEM and non-STEM, and can be further developed as a project in class.

Teachers can opt to instruct students about the Earth, how it rotates and its relation to the Sun. From there, they can step up and further examine phenomena like the temperature, which factors drive temperature to rise, urbanization and industrialization, but also natural disasters like wildfires, acidic oceans, storms, and flooding.

In order to examine and research the above in class, an understanding of various notions and principles from subjects like mathematics, physics, biology, and chemistry are required. In addition, historical knowledge and understanding of politics might contribute towards understanding why actions that contributed to climate change were supported and adopted during each chronological period, and how IT and computer science can help us monitor and predict future trends. Consequently, through the selection of this subject, students have the opportunity to be

exposed in a large variety of resources and knowledge that will intrigue their curiosity and introduce them to integrated STEM teaching that also includes non-STEM subjects. The same time, the interdisciplinarity of STEM is illustrated.

## NEXT STEPS

### Primary / Secondary teachers

Eleven teams consisting of three teachers each, have been selected in order to participate in the STE(A)M IT project. Each team is expected to create a Learning Scenario based on the STE(A)M IT approach. The Learning Scenarios will be tested in other schools and updated based on the feedback received by teachers and students. They will then be used in two online courses for teachers, as good examples, that will be launched in October 2020.

### Ministries of Education

The Ministries of Education STEM Representatives Working Group (MoE STEM WG), coordinated by European Schoolnet under the Scientix initiative, promotes discussion and exchange between Ministries of Education regarding their STEM education policies and the common points. The long-term goal of this working group is to help lay the foundations for medium and long-term strategies and activities between Ministries of Education and European Schoolnet in the field of STEM education, following an agenda that addresses the priorities that the Ministries have set and their main interests. In that respect, the representatives will be providing feedback on the findings and results of the STE(A)M IT project, especially regarding the Integrated STEM Framework, give insight on the latest developments in their respective countries as an attempt to coordinate efforts in having a common agenda, and make the results of research available to all teachers in order to facilitate their work during the project.



This will facilitate the promotion and mainstreaming of best practices.

## Industry

European Schoolnet is the coordinator of STEM Alliance<sup>10</sup> and has established the Future Classroom Lab<sup>11</sup> in 2012. Both the STEM Alliance and the Future Classroom Lab have very close ties with industry representatives, who are expected to contribute during the phases of validation and piloting. The approach by industry representatives done by those two initiatives differs but the aim is common, and that is supporting STEM education with innovative technologies and reinforcing positive messages about STEM careers. When it comes to STEM Alliance, this is additionally ensured by the support of professionals who frequently participate in Science Projects Workshops and webinars to give insights about their industry and career paths. This way, teachers of STEM subjects have direct feedback and insight to how they can adapt their lessons, activities, and selection of materials in order to substantially promote STEM education and careers, providing real examples of how STEM subjects can be applied in education and life.

When it comes to the Future Classroom Lab, a number of industry partners, representing both medium-sized but also larger companies, present their most recent and relevant technologies that can be applied in classrooms, focusing on different modes of learning, transforming efficiently the educational spaces, and facilitating teaching and learning. The technologies and companies represented in the Future Classroom Lab vary significantly from the latest equipment to be used in classrooms to educational robots and solutions that promote programming.

## Collaboration with other initiatives

Finally, the same way that STEM disciplines do not work alone, STE(A)M IT will continue collaborating with other European Commission funded projects like STEAMonEDU, CHOICE, and Learn STEM, organisations like NHL STENDEN, the International STEM Awards, Let's talk Science, Texas Instruments, and LEGO Education, and any other interested parties in developing the first integrated European framework for STEM education and supporting activities.

10. <http://www.stemalliance.eu/?resourceId=12010>

11. <http://fcl.eun.org/home>

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## ANNEX: STAKEHOLDER QUESTIONNAIRE ITEMS

### 1. Concept

- *I have a clear understanding of what integrated STEM education is*
- *I have heard colleagues talking about integrated STEM education*
- *I have talked with colleagues about integrated STEM education*
- *I know how to develop an engineering design task for my students*
- *I can employ teaching approaches that foster integrated STEM education*

### 2. Responsive Instruction

- *I feel competent to design an integrated STEM lesson plan*
- *It is easier for me to design an integrated STEM lesson plan based on a given example*
- *I feel competent to orchestrate an integrated STEM lesson*
- *I can offer support to my students when they enact an integrated STEM learning task*

### 3. Resources available

- *There are enough resources and material available for integrated STEM education*
- *The resources and material available for integrated STEM education are useful*
- *The resources and material available for integrated STEM education can be easily implemented in everyday school practice*
- *The resources and material available for integrated STEM education fit with the national curriculum*
- *The resources and material available for integrated STEM education are interesting for students*

### 4. Pedagogical Design

- *Many teachers are willing to collaborate with their colleagues in designing lesson plans for integrated*
- *STEM education*
- *Collaboration between teachers can deliver more interesting resources and material for integrated*
- *STEM education than are currently available*
- *Many teachers are willing to collaborate with stakeholders in designing lesson plans for integrated*
- *STEM education*
- *Collaboration between stakeholders can deliver more interesting resources and material for*
- *integrated STEM education than are currently available*

### 5. Funding

- *Industry partners should allocate more funding to integrated STEM education*
- *Ministries of Education in Europe should allocate more funding to integrated STEM education*
- *There are many opportunities to support integrated STEM education by funding at the national level*
- *There are many opportunities to support integrated STEM education by funding at the European level*

### 6. Professional development

- *Professional development programmes offer enough opportunities for engaging teachers in integrated STEM education*
- *Professional development programmes promote collaboration among teachers for designing*



lesson plans in integrated STEM education

- Professional development programmes promote collaboration among stakeholders for designing lesson plans in integrated STEM education
- Professional development programmes focus much more on each one of the STEM disciplines than on their integration

#### 7. Pre-service teacher education

- *Pre-service teacher education programmes offer enough opportunities for engaging teachers in integrated STEM education*
- *Pre-service teacher education programmes promote collaboration among teachers for designing lesson plans in integrated STEM education*
- *Pre-service teacher education programmes promote collaboration among stakeholders for designing lesson plans in integrated STEM education*
- *Pre-service teacher education programmes focus much more on each one of the STEM disciplines than on their integration*

#### 8. Organizing principle

- *Engineering design education can be used as an organizing principle in integrated STEM education*
- *Project-based learning can be used as an organizing principle in integrated STEM education*
- *Robotics can be used as an organizing principle in integrated STEM education*
- *Each STEM discipline can serve as an organizing principle for integrated STEM education*

#### 9. Main barriers to integrated STEM education

- *Average school culture and environment does not favour integrated STEM education*
- *Everyday school practice does not favour integrated STEM education*
- *Average teacher skills do not favour integrated STEM education*
- *Current curriculum requirements do not favour integrated STEM education*
- *Current assessment methodologies for students do not favour integrated STEM education*

#### 10. Change

- *All stakeholders agree that reform is needed to foster integrated STEM education*
- *Drastic institutional change is needed for integrated STEM education*
- *A national strategy for integrated STEM education is missing*
- *Integrated STEM education should be a priority for Europe*

#### 11. Careers

- *An integrated STEM approach is important for STEM careers*
- *Thinking STEM subjects together helps solve current challenges in the industry*
- *The future workforce in my sector requires interdisciplinary thinking*
- *Teaching STEM subjects in an integrated way helps students develop skills needed in the industry*





# STEAM IT

## AN INTERDISCIPLINARY STEM APPROACH

This publication corresponds to Deliverable D2.1 Integrated STEM teaching state of play of the STE(A)M IT project. The aim is to provide an overview of the existing scientific and grey literature research on the topic while laying the foundation for the development of the first Integrated STE(A)M education framework. The report presents in detail the results of the SWOT analysis performed on the topic that reveals the opportunities and challenges ahead.

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