June 2023

STEAMTeach
Science | Technology | Engineering | Arts | Mathematics

O1: State of the Art on STEAM Teacher Training Toward a Transcultural Professional Development Framework

Co-funded by the Erasmus+ Programme of the European Union

PROJECT

PROJECT ACRONYM	STEAMTeach
PROJECT TITLE	STEAM Education for Teaching Professionalism
PROJECT REFERENCE	2020-1-ES01-KA201-082102
START DATE	1st October 2020
KEY ACTION	Cooperation for innovation and the exchange of good practices
ACTION TYPE	Strategic Partnerships for school education

INTELLECTUAL OUTPUT DETAILS

INTELLECTUAL OUTPUT (IO) NUMBER AND TITLE	O1: State of the Art on STEAM Teacher Training Toward a Transcultural Professional Development Framework
RESPONSIBLE ORGANISER OF THE IO	Johannes Kepler University
START DATE	1st October 2020
END DATE	30th June 2023
MEDIA	Text File and Publications
DISSEMINATION LEVEL	Public

REPORT DETAILS

VERSION	1.0
DATE	30 June 2023
MAIN AUTHORS' NAME AND EMAIL ADDRESS	José Manuel Diego-Mantecón[1] (diegojm@unican.es), Zaira Ortiz-Laso[1] (ortizz@unican.es), Tony Houghton[2] (ajh249@gmail.com), Imam Fitri Rahmadi[2] (imam.rahmadi@jku.at), Dimitris Diamantidis (dimitrd@eds.uoa.gr), Zsolt Lavicza[2] (zsolt.lavicza@jku.at), Chronis Kynigos[3] (kynigos@eds.uoa.gr), Kristof Fenyvesi[4] (fenyvesi.kristof@gmail.com), Takumi Yada[4]

Co-funded by the Erasmus+ Programme of the European Union

This project has been co-funded by the Erasmus+ programme of the European Union under grant no. 2020-1-ES01-KA201-082102.

	(tayada@jyu.fi), and Vilmos Vass[5] (vvass@metropolitan.hu)
CONTRIBUTING INSTITUTIONS	[1]Universidad de Cantabria, [2]Universitat Linz, [3]Ethniko Kai Kapodistriako Panepistimio Athinon, [4]Jyvaskylan Yliopisto, [5]Budapesti Metropolitan Egyetem
REVIEWED BY	José Manuel Diego-Mantecón[1] (diegojm@unican.es), Zaira Ortiz-Laso[1] (ortizz@unican.es)
STATUS	Submitted

Co-funded by the Erasmus+ Programme of the European Union

This project has been co-funded by the Erasmus+ programme of the European Union under grant no. 2020-1-ES01-KA201-082102.

STEAMTeach

TABLE OF CONTENTS

Co-funded by the Erasmus+ Programme of the European Union

This project has been co-funded by the Erasmus+ programme of the European Union under grant no. 2020-1-ES01-KA201-082102.

Co-funded by the Erasmus+ Programme of the European Union

This project has been co-funded by the Erasmus+ programme of the European Union under grant no. 2020-1-ES01-KA201-082102.

1 INTRODUCTION

The success of the Erasmus+ Project KIKS (Kids Inspiring Kids in STEAM, 2015-1-HU01-KA201-013611) was in no little part due to the enthusiastic and expert contribution of our teachers. This highlighted the importance of teachers including the need to also engage those less confident or otherwise enthusiastic about STEAM. Hence the focus of this follow-on project STEAMTeach (STEAM Education for Teaching Professionalism) is the teachers themselves and how we might work with teacher trainers and others to develop a programme of Transcultural STEAM Professional Development for in- and pre-service teachers. In particular, STEAMTeach aimed to:

- Design a Transcultural Professional Development Framework
- Use the framework for developing and implementing Teachers' STEAM Training Course Programmes
- Test the local and trans-cultural effectiveness of these STEAM programmes by assessing the instruction of our trained teachers in their classrooms with students

This document presents the process of designing a transcultural professional development framework. Some sections are further developed in well referenced publications originated in the framework of STEAMTeach project; including **An attempt to evaluate STEAM project-based instruction from a school mathematics perspective** in *ZDM – Mathematics Education*, **Toward a STEAM professional development program to exploit school mathematics** in *Proceedings of the Twelfth Congress of the European Society for Research in Mathematics Education (CERME12)*, and **STEAMTEACH Austria: Towards a STEAM Professional Development Program** in *International Journal of Research in Education and Science* (see Annex 1: Publications for more details). The main objectives to be achieved were:

- O1.1 Identifying innovative and effective learning methodologies, and tools related to STEAM Teach, as well as the EU key competencies that can enhance through the STEAM approach
- O1.2 Identifying main issues obstructing STEAM Teacher Training
- O1.3 Developing a Transcultural STEAM Teaching Development Framework

Co-funded by the Erasmus+ Programme of the European Union

This project has been co-funded by the Erasmus+ programme of the European Union under grant no. 2020-1-ES01-KA201-082102.

- O1.4 Refining the initial framework from an iterative process, after the design and implementation of several courses and STEAM projects in the classroom.

The document starts with the rationale for the evolution of STEM to STEAM (§2). Then, three candidate learning methodologies to be used for implementing STEAM education are described as part of the O1.1 (§3). In the next section related to O1.2, we identify the main issues obstructing the implementation of STEAM education in five European countries (Spain, Austria, Hungary, Greece, and Finland) (§4). According to the above results, we selected the learning methodologies for training teachers during the STEAMTeach project (§5). Finally, we designed and refined a transcultural STEAM professional development framework for training teachers (§6), as part of O1.3 and O1.4.

2 FROM STEM TO STEAM

In recent years, Science, Technology, Engineering and Mathematics (STEM) education has received significant attention. STEM education, previously known as STS [Science, Technology and Society] and SMET [Science, Mathematics, Engineering and Technology], became in response to the social needs stated by different U.S. organizations in the 1980's (Kim et al., 2019). These social needs have usually concerned two issues: competent students' training, and students' recruitment for STEM professions. The provision of competences allows "full participation in society and successful transitions in the labour market" (European Commission, 2018, p. 1). In addition, it is considered that a competent society guarantees the national economic success, requiring well-qualified people able to address current and future changes (Díez-Ojeda et al., 2019; English et al., 2016; Thibaut et al., 2019). As a consequence of these changes, for example, many primary school children will be working on professions that do not exist currently (European Commission, 2017) as future companies will demand STEM professionals (Conde et al., 2020). We are aware that there is an insufficient number of professionals in STEM careers worldwide (e.g., CEDEFOP, 2014; Thomas & Watters, 2015). This trend seems to keep on future generations of workers, i.e., primary and secondary school students, as they seem not to be interested in pursuing STEM-related careers (Kennedy et al., 2014; Toma, 2020; Toma & Meneses-Villagrá, 2019), by identifying mal-adapted or negative beliefs about subjects such as Mathematics (Diego-Mantecón et al., 2019) and Physics (Toma & Meneses-Villagrá, 2019).

STEM education has turned out to be effective for cognitive and affective learning (Diego-Mantecón et al., 2020; Han et al., 2016; Kang, 2019; Martínez, 2017; Toma & Greca, 2018; Tseng et al., 2013). In the last years, STEM acronym has often been modified into STEAM education, incorporating 'Arts' to the STEM subjects. This implies primarily combining knowledge and skills from the humanities, social sciences, and art disciplines (Colucci-Gray et al., 2019; Diego-Mantecón et al., 2021). The addition of arts can lead to creativity, ethics, aesthetic, and innovation by combining thinking from the arts and STEM-related disciplines (Colucci-Gray et al., 2019; Kim et al., 2019; Quigley et al., 2020b). STEAM education also promotes intercultural knowledge (Chu et al., 2019; Diego-Mantecón et al., 2021).

In general, STE(A)M educational practices are defined as the ones integrating content and skills from science, technology, engineering, (arts), and/or mathematics. These practices are usually framed in real world contexts promoting problem solving, inquiry-based, and collaborative learning (Martín-Páez et al., 2019; Thibaut et al., 2018). However, some discrepancies emerge on whether STE(A)M practices should combine two (or more) disciplines (Carmona et al., 2019; Maass et al., 2019a) or should integrate all (Martín-Páez et al., 2019; Toma & García-Carmona, 2021). Although, STEM or STEAM, hereinafter STE(A)M, education have been promoted through different initiatives, meaningful school-intervention habits have not reached a large implementation, especially at secondary education level (Diego-Mantecón et al., 2021).

3 LEARNING METHODOLOGIES USED IN STEAM EDUCATION

STE(A)M is an emerging approach linked to various learning methodologies such as project-based learning (Han et al., 2015, 2016; Diego-Mantecón et al., 2019, 2021), games (García-Ruiz et al., 2018) and citizen science (Senabre et al., 2018). STE(A)M education benefits could be influenced by the learning methodologies employed to implement the educational practices. Below, we characterize learning methodologies that are effective for implementing STE(A)M activities.

3.1 Project-based learning[1]

Our understanding on project-based learning (PBL) has been published in open access in the *ZDM – Mathematics Education* journal. The publication was done with the collaboration of an external researcher specialised in PBL (Theodosia Prodromou, University of New England). PBL is a student-centred method in which students adopt an active role and teachers act as facilitators of the learning process. Several studies in different contexts have shown that project-based learning is effective to develop different dimensions of mathematical competence and competence in science, technology, and engineering (e.g., Afriana et al., 2018; Blanco et al., 2019; Chai, 2019; Diego-Mantecón et al., 2019, 2021; Han et al., 2016). Diego-Mantecón et al. (2021) have also confirmed that the combination of STEAM project-based learning with the KIKS format— based mainly on the development of the project in English and the dissemination of the project through different audiences —facilitate the development of all eight key competences. Thibaut et al. (2018) contemplated five PBL dimensions, as follows: content integration, problem-centred, inquiry-based, design-based, and cooperative learning.

Content integration implies combining knowledge and skills from STE(A)M disciplines, with one discipline playing a dominant role (Martín-Páez et al., 2019). Three approaches to content integration are usually described: multidisciplinary (Conradty & Bogner, 2019; Kim, 2016), interdisciplinary (Chaaban et al., 2021) and transdisciplinary (Herro & Quigley, 2017; Quigley et al., 2020b). The multidisciplinary approach entails learning content separately in each discipline but within a common theme (English, 2016; Gresnigt et al., 2014). The interdisciplinary approach juxtaposes content from at least two disciplines, establishing explicit connections (Gao et al., 2020). In the transdisciplinary approach "the curriculum transcends the individual disciplines" (Gresnigt et al., 2014, p.

[1] This section is widely developed in the following article:
Diego-Mantecón, J. M., Prodromou, T., Lavicza, Z., Blanco, T. F., & Ortiz-Laso, Z. (2021). An attempt to evaluate STEAM Project-Based Instruction from a school mathematics perspective. *ZDM - Mathematics Education*, *53*(5), 1137-1148. https://doi.org/10.1007/s11858-021-01303-9

52) and knowledge and skills are applied in real-world situations (English, 2016; Gresnigt et al., 2014). Apart from these three approaches, some authors considered the monodisciplinary one (Gao et al., 2020), which is not a STE(A)M integrated approach as it incorporates content from a single discipline (Toma & García-Carmona, 2021). The second dimension, *problem-centred*, implicates solving problems in authentic contexts (Conradty & Bogner, 2019; Margot & Kettler, 2019). These problems tend to be open-ended and ill-defined, encouraging creative solution pathways (Herro et al., 2019) and multiple answers (Diego-Mantecón et al., 2021). *Inquiry-based learning* seeks to promote processes such as questioning, hypothesizing, experimenting, and deducing conclusions (Pedaste et al., 2015; Thibaut et al., 2018). In the design-based dimension, engineering and technology are central (Li & Schoenfeld, 2019): technology is viewed as a tool to create and test artefacts (Akgun, 2013) and engineering is viewed as the context to apply mathematical and scientific content (Margot & Kettler, 2019). *Design-based learning* fosters problem solving and creativity, facilitating mathematical knowledge acquisition (Li & Schoenfeld, 2019), reasoning (English & King, 2019), and positive attitudes toward mathematics (Diego-Mantecón et al., 2019). The last dimension, *collaborative learning*, emphasizes teamwork — "students working together for a common purpose" (Chapman et al., 2010, p. 39). According to Chu et al. (2019), teamwork helps students to examine phenomena and to relate new knowledge to existing knowledge. It also provides opportunities for generating discussions, solving conflicts, and communicating openly (Chaaban et al., 2021).

PBL has been effectively implemented in the context of European projects such as KIKS (Erasmus+) and STEMforYouth (Horizon2020) (Diego-Mantecón et al., 2021). Different dimensions of PBL, as for example, inquiry-based learning and problem-based learning has been already in projects such as MASCE (Maass et al., 2019a, 2019b).

3.2 Games and user centred design

Rahmadi et al. (2021) reports that user-generated microgames for supporting learning may result in higher take-up. The idea of user-generated microgames for supporting learning in general could be extended to support STEAM learning which can be so-called *learner-generated microgames;* students create their own microgames (as the Arts) within integrated STEM subjects.

Co-funded by the Erasmus+ Programme of the European Union

This project has been co-funded by the Erasmus+ programme of the European Union under grant no. 2020-1-ES01-KA201-082102.

3.2.1 Gamification

Gamification is an emerging educational initiative to enrich learning engagements and experiences. The simplest and most familiar definition of gamification is the application of game-design elements and game principles in non-game contexts (Deterding et al., 2011; Huotari & Hamari, 2012; Robson et al., 2015). Furthermore, Kapp (2012) defines gamification into more detail as using game-based mechanics, aesthetics and game thinking to engage people, motivate action, promote learning, and solve problems. The use of gamification may provide learners with richer learning activities, behaviours, and experiences through several elements of games such as feedback, goals, badges, point system, leader board, and user levels (Huotari & Hamari, 2017). From the definitions, gamification sounds promising to be applied in various learning contexts.

Gamified learning has many benefits and drawbacks. In general, learning with gamification has a positive effect on cognitive, motivational, and behavioural learning outcomes and it works surprisingly well in schools (Sailer & Homner, 2020). Gamification powers learners to track their learning progress in comparison to their own or their peers' achievement (Kiryakova et al., 2014). Learning environments that are equipped with game elements really appeal to learners particularly toward their enjoyment and engagement in learning (Filippou et al., 2018). Still, however, there are disadvantages of gamification for learning. According to Faiella & Ricciardi (2015), gamification focuses too heavily on extrinsic motivation, over gamified learning decreases learning engagements, and the effects of gamification greatly depend on the users. Both the positive and negative sides of gamification should be considered seriously in learning practices.

Game elements and principles may also be integrated into STEAM learning. Kummanee et al. (2020) develop STEAM gamification learning model to enhance creativity and innovation skills of vocational students. A gamified evaluation was used by Boytchev & Boytcheva (2019) to evaluate students' understanding of STEM-related subjects in a higher education context. A literature review on the implementation of gamification within STEAM fields in higher education reveals that engagement is the main key dependent variable to see its effectiveness (Ortiz et al., 2016). Despite the contexts, it seems that gamification is not a stand-alone methodology, which the application should be embedded in existing learning environments.

3.2.2 Serious games

Serious games are defined as games designed and developed specifically for learning purposes (Richey, 2013: 86). This field is extensively discussed in a book called *Serious Games* by Abt in 1970. Serious games offer "a rich field for a risk-free, active exploration of serious intellectual and social problems" (Abt, 1970, p. 13). The term serious is intended to reflect the purpose and reason of the game regardless of content. Serious games provide users with fun and meaningful experiences reaching up to the emotional level as well as to offer immediate feedback and adaptability resulting in the higher goals achievement level (Dörner et al., 2016). According to Mildner and 'Floyd' Mueller (2016:61), games in serious or just entertaining ways share common elements including play, rules, storytelling, social factors, and learning. However, it does not mean serious and leisure games are the same. Serious games focus on the important element of learning whilst for entertainment games; fun is the most important aspect (Susi et al., 2007). The power of serious games is in the ability to create dedicated games content for learning rather than utilising existing leisure games (de Freitas, 2006).

Serious games have several advantages and disadvantages in supporting learning and instruction. On the one hand, games have the possibilities to provide active, real, and mediate feedback on the cognitive learning process as well as to motivate and engage students in learning (de Freitas, 2006; Mayer, 2014). Furthermore, it is evidence that games boost learning performances, improve cognitive skills, and are more effective than conventional media for learning (Mayer, 2016 & 2019). On the other hand, there are some barriers to the integration of educational games into formal learning environments. The constraints are including but not limited to the long-duration gameplay and minimum of adequate technologies (Rice, 2007), lack of teacher's innovativeness and best practices (Ketelhut & Schifter, 2011), and limited games that match to learning objectives (Watson & Yang, 2016). Teachers have a very strict and limited time practicing game-based learning in the classroom. Therefore, one sensible solution to this is to integrate educational microgames (Rahmadi et al., 2021) instead of more general learning games for teaching and learning in schools.

This project has been co-funded by the Erasmus+ programme of the European Union under grant no. 2020-1-ES01-KA201-082102.

Games can be integrated for supporting learning in two different ways, to play games or to create games (Rieber et al., 2009; Siko & Barbour, 2012). The first strategy is by far the most common ones. Teachers use games for teaching while students play games for the means of learning. Creating games as media for learning and instruction appears to be the more advanced level and this looks potential to support integrated learning such as for science, technology, engineering, arts and mathematics (STEAM) education. Games act as the arts to bridge connection among other STEM subjects (G.A. STEM, 2019). By developing games, students learn interdisciplinary science, technology, engineering, arts and mathematics.

3.2.3 Educational live action role playing

Live action role-playing (larp) is a new kind of traditional role-playing, which immerses participants in detailed roles that facilitate active experimentation and improvisation in imaginary circumstances (Lacanienta, 2020). It is characterised with embodied role-based interactions and physically performed role-play (Harviainen et al., 2018). Larp participants immerse themselves with thorough character creation, personal interactions, and sometimes even props and costumes. The larp activities take place in a fictional reality shared with other participants. Larp is often associated with role-playing that is rooted in the essential human activity of childhood-pretend play. The role-playing can thus be seen as a simulation but with simpler technologies (Bowman, 2014). The concept of live action role-playing is also linked to games and drama. However, games have some mechanics and drama is more theatrical. Apart from the differences, the terms are interrelated to each other owing to cultural evolutions.

The use of larp is becoming more and more popular in education context thus it is so-called educational live action role-playing or edu-larp. An educational larp is a pedagogical activity where students take on character roles in pre-written scenarios designed to facilitate self-motivated learning, as well as teach pre-determined knowledge in a contextual framework (Vanek & Peterson, 2016). Larp in education has multiple upsides and downsides. The major benefit of larp is teacher-friendly and content-friendly. Larp is very easy to be used by teachers and to be integrated with the core content of school textbooks (Michał, 2013). Larp is an effective tool for communities to engage with alternative realities together and it is a flexible system that can be combined with new

Co-funded by the Erasmus+ Programme of the European Union

This project has been co-funded by the Erasmus+ programme of the European Union under grant no. 2020-1-ES01-KA201-082102.

technologies such as mobile, computing and augmented reality technology (Bienia, 2012). One main disadvantage of edu-larp is due to the long duration of larping but have very little time for post-larp debriefing (Michał, 2013). Integrating the edu-larp method into a traditional curriculum requires streamlining during the briefing and debriefing or reframing process (Bowman & Standiford, 2015).

Edu-larp may also be used for science, technology, engineering, arts and mathematics (STEAM) learning. Angeles (2016) designed larp activities as part of a STEAM summer program for indigenous youth. The results show that larp can be both engaging and bridging for people of many different communities in the STEAM program. Edu-larp games have potential for teaching and learning in STEAM subjects since it can bring students from across disciplines to work and pool their knowledge together to solve and contribute to something greater (Clarke et al., 2016). Although there are few studies exploring edu-larp in STEAM learning, the possibility of edu-larp to support STEAM learning should be further investigated. Edu-larp was commonly used for language, humanities, and social studies learning, thus now is time to experiment edu-larp for integrated STEAM teaching and learning. Larps are being designed to learn STEM subjects with a special focus on mathematics, as part of the Erasmus+ Project *Mathematics EduLarp*.

3.3 Citizen Science with co-creation process

Citizen Science (CS) has been traditionally described as a research paradigm in which members of the public (volunteers, non-experts, amateurs) take part in scientific activities initiated by scientists, often related to natural and physical sciences such as identification of invasive species and classification of galaxies (Herodotou et al., 2018). The term 'Citizen Science' was introduced by Alan Irwin (1995), who used it to describe expertise that exists among those who are traditionally seen as ignorant 'lay people', as it is quoted in the 'Science for Environment Policy In-depth Report: Environmental Citizen Science' (Science Communication Unit, University of the West of & England, Bristol, 2013). In the beginning of the past decade, Bonney and colleagues redefined the term, into a methodology for research (Bonney et al., 2009); more specifically, a technique that includes the help of the public in gathering scientific data. The case of Bonney came from Ornithology. The degree of public engagement with CS varies from initiating a research activity to contributing to processes of data collection and analysis (Shirk et al., 2012) with the latter being prominent in the field. Although the initial approach on citizen's contribution was around data gathering, recent CS practices involve the public in scientific activities like analysis, or devising personally meaningful investigations (Herodotou et al., 2018; Senabre et al., 2018). Efforts are also made in expanding the application of CS across disciplines, like social sciences, indicating the viability of this approach to supporting citizen-led participation across disciplines (Dunn & Hedges, 2018).

Co-creation is a specific form of design-based learning. It is obvious that co-creation emerges in teams which are composed of students from different disciplines, an 'end-user' and industry participants (optionally). The end-user is a 'client' with a specific need, who is in the centre of the design activities, meaning that the team members (including the end-user) jointly identify solutions that meet the needs of the client through designing, making, and improving prototypes. In this sense, the outcome of the design process addresses a real existing need, and consequently serves an existing market, broader or limited, big, or small. The aspect of learning is emphasized, in co-creation since the design process leads to acquisition of knowledge and skills. Thus, because of the participants' discipline diversity; there is knowledge/skill networking within and beyond specific discipline circles. Therefore, co-creation is closely related to education; this relationship is increasingly seen as an adequate methodological tool for the challenges around learning, described above, with elements of inclusion. However, co-creating is neither an easy nor straightforward activity. Issues arise around the coaching co-creation teams, which is demanding, although challenging and the risk of limited exploitation of promising results within a systemic educational environment.

On the one hand coaching co-creation teams is labour intensive and requires knowledge on design methodologies, to meet real end-user needs. Thus, its implementation may be restricted, and sometimes insufficient or inadequate, as a process. On the other hand, in a regular educational environment where the design is partially based on the educational setting, co-creation may adopt the characteristics of a systemic learning activity; when a semester ends, the exploitation of co-creation results, i.e., market-dissemination, commercial effect, is interrupted.

Co-funded by the Erasmus+ Programme of the European Union

This project has been co-funded by the Erasmus+ programme of the European Union under grant no. 2020-1-ES01-KA201-082102.

Citizen science with a co-creation process has been successfully implemented in the context of the European project STEMforYouth, funded under the programme Horizon 2020.

4 IDENTIFYING ISSUES OBSTRUCTING THE IMPLEMENTATION OF STE(A)M EDUCATION IN EACH PARTNER COUNTRY

In each participant country, semi-structured interviews were conducted to STEAM trainers to know the trainers' current practices, their challenges when implementing STEAM activities, as well as their recommendations for overcoming those challenges. The Spanish team designed two guides for the semi-structured interviews; one for STEAM trainers and other one for STEAM trainers who are also secondary education teachers. See Annex 2, Semi-structured interview guide, for more details about the semi-structured interviews.

4.1 Spain

Below, we summarize the results obtained from the interviews conducted in Spain. They were conducted face-to-face by three STEAMTeach Spanish researchers between January 2021 and February 2021.

4.1.1 Sample

The Spanish sample included five STEAM trainers, four of them were also teachers at the secondary education stage. Two of them also qualifies pre-service teachers from early childhood to secondary education at the university. Three of the trainers have management positions at their high school: headmaster, head of studies, and head of the science department. Four trainers are male and one of them is female. Their age ranged from 28 to 50, all of them with more than five years of experience on STEAM training. These trainers hold pure mathematics, physics, biology, and civil engineering university bachelor's degrees. They usually apply project-based learning and inquiry-based learning. The table below shows characteristics of the five interviewees.

	Sex	Age	Background	Secondary education teacher?	Management position at school?	Training pre-service teachers?
Trainer 1	Male	38	Biology	✓	✓	
Trainer 2	Male	43	Physics	✓	✓	
Trainer 3	Male	50	Mathematics	✓		
Trainer 4	Male	48	Civil Engineering	✓	✓	✓
Trainer 5	Female	28	Mathematics			✓

4.1.2 Methodologies for delivering STEAM education

All Spanish trainers agreed that employing active learning methodologies is essential for delivering STEAM education. Two interviewees explicitly expressed that the methodology choice depends on different factors. These two participants indicated that teacher' experience and skills are crucial. In this sense, experienced teachers in the implementation of active learning methodologies could provide students with educational practices requiring long periods of time, while non-experienced teachers should begin with short period practices. Both concurred that teachers need skills that differ from the ones required in a traditional approach. These skills include time management and participation encouragement. Only one of these two trainers indicated that students' characteristics must be also considered, highlighting that how students usually learn should be a key element in the methodology choice.

The most recommended methodology was project-based learning, being selected by 4 out of 5 participants. Through the trainers' responses when talking of project-based learning, different dimensions of this methodology introduced in §3.1 can be identified. All these trainers positively valued that content from different disciplines can be addressed. In addition, they highlighted that the learning process can be framed in real word contexts. In particular, one of them suggested that the project nature (open-ended and unstructured) helps students understand that problems can be approached and solved applying different strategies. All trainers also considered essential teamwork. Two trainers emphasized on the importance of incorporating inquiry-based learning during the project implementation. One of these two trainers, who teaches science subjects (biology, physics, and chemistry) at high school, reflected on planning experiments to involve students in data collection and analysis for explaining scientific phenomena. He pointed out that these processes contribute "to deeper and significant learning than following a traditional approach" (male, aged 38). The other trainer, who is a mathematics and technology teacher, supported inquiry-based learning relying on the benefits of questioning and challenging students. Three interviewees coincided with incorporating design-based learning through the engineering-design process, as a natural way for guiding the project. Sometimes, short educational practices based on games are introduced during the project development for motivating students, as a trainer declared during the interview.

Inquiry-based learning was mentioned by two Spanish trainers, without mentioning project-based learning or as an alternative to project-based learning. Both interviewees agreed that this methodology is useful for questioning students and reflecting on previous knowledge. In this sense, one of them expressed it offers opportunities for students to be involved in planning research questions, analysing data, and formulating conclusions. This trainer also indicated that it is important to provide students with hands-on activities, i.e., promoting design-based learning.

Finally, problem-based learning emerged during the interview of one trainer. The trainer explained that it allows contextualizing new concepts and facts in real life situations achieving a more significant comprehension.

4.1.3 Challenges and solutions

Challenges identified by Spanish teachers and proposed solutions are summarized according to the following dimensions: 'curriculum', 'activity design and implementation', 'teacher' training', 'support from the educational context and students' families', and 'students' motivation'.

Curriculum

The main challenge identified by all interviewees for implementing STEAM education was the structure of the Spanish curriculum. Particularly, they identified mainly three obstacles: the subject-fragmentation, the timetable, and the time devoted to design activities and to establish collaborations. Regarding the subject-fragmentation, four trainers stated that there is not an independent subject designed for applying content in an integrated way. Teachers explained that when implementing integrated activities, you incorporate content from other subjects, adding more content than the one expected for addressing in your subject. It is even difficult for them to cover all content from their subject, so addressing more content, having the same time, is one of the main challenges to overcome. A trainer also pointed out that subject-fragmentation does not favour the assessment, as officially content from one subject must be only evaluated. In relation to the timetable, two trainers explained that the fragmentation of the school hours, resulting usually in lessons of about 45-50 minutes, does not facilitate the implementation of active learning methodologies. This time is not enough because the classroom must be frequently adapted to work in groups at the beginning and the end of the lesson. Thus, there really is around 40 minutes for formulating a problem, discussing with students, performing experiments, extracting conclusions, and so on. Finally, four interviewees complained about the short time available for preparing lessons and establishing collaboration with other teachers. They argued that the design and supervision of STEAM activities is time consuming, and it is not enough with the time planned for preparing activities. In addition, teachers explained that the 1-hour established for the meeting of the department is not enough in the case of STEAM education as it requires coordination between several departments, and there is not time recognised for that purpose. Programming meetings with teachers from other departments would facilitate the coordination between teachers, and consequently the implementation of STEAM education.

Activity design and implementation

Approaching STEAM content for making it accessible for all students was identified as a challenge by all interviewees. Particularly, one of them expressed that "it is really difficult to design an activity covering curricular content connecting to students' previous knowledge" (male, aged 50). Three trainers recommended retrieving and adapting activities designed by experts in STEAM education in the framework of national and international projects. This contributes to reduce "uncertainty as the activity design may be the hardest part of the STEAM education" (male, aged 48), especially in non-experienced teachers. Two trainers spoke also about the difficulty to supervise and guide students during the solution process. In particular, one of them highlighted that due to problems' nature (open-ended), students usually propose solutions or pathways that are not feasible. It is difficult to deal with this situation because students often feel disappointed when the solution is examined, and the teacher reports that although the pathway for attaining the solution is original, and even valid, it is not possible to execute it in the school context. This trainer verbalized: "it should not improvise because problems always arise and that is synonymous with lack of control in the classroom" (male, aged 38). Time management also emerged during three interviews, indicating that it is important to attempt to keep the time allocated for every problem.

Teacher' training

Three trainers expressed that teacher' initial training is essential for promoting meaningful learning. These three interviewees stated that even teachers that have already implemented STEAM education for a long time cannot overlook continuous training. They advocated involving these teachers in professional development courses or conferences. One of the trainers was concerned with the risks of allowing teachers, who have usually received pedagogical training on one subject, to instruct content from other subjects. Due to that reason, this trainer gave a priority to collaborate with other teachers. Another interviewee, who is also school head of studies, recommended qualifying three or four teachers from a high school, so that in the future these teachers could act as trainers of the remaining teachers.

Support from educational context

Three trainers conveyed teachers need to collaborate with peers or experts to effectively and properly exploit the disciplines involved in a project. One of these subjects expressed that "the more approaches the activity receives, the more it will be enriched" (male, aged 43). Two out of these three interviewees perceiving support from their educational centre recommended searching for collaboration within the educational centre. Differently, the other trainer, not perceiving support from their own context, indicated that the support can be also gotten through educational communities aimed at supporting STEAM education. A trainer, who is currently supported by his high school colleagues, explained that initially he was not able to collaborate with other teachers from his high school because they instructed under a traditional approach. However, after the management team promoted STEAM education, his colleagues modified their attitudes towards collaboration. In this sense, other two interviewees revealed that the support from the management team, although is not a necessary condition, is differentiating. This team can offer opportunities for improving teacher training, setting up rooms in the high school, as well as funding the requested materials.

Students' motivation

All participants showed concern about the difficulty to engage students along the whole solution process. Some of them related the lack of students' engagement to their little experience for working under active methodologies. In this sense, an interviewee relayed students are not usually working on solving real world problems, instead they are usually solving tasks proposed by textbooks. Two of them highlighted that the project thematic must be interesting and close for students to involve them in the learning process. All subjects concurred with the idea that students are more motivated when they develop the projects or inquiries with the aim of disseminating the results in front of an audience unconnected to the context of their own school. A participant suggested that students' motivation really rises when there is an award, proposing to enrol students in competitions.

Support from families

One of the interviewees, who is also a high school teacher, expressed that initially families are reluctant to have their relatives taught with active learning methodologies. Families are often expecting that their relatives learn under the same approach that they were trained, i.e., a traditional approach. In particular, families do not feel confident with active methodologies because most of the work is carried out during the school day, and families do not monitor the students' tasks. This trainer recommended meeting with families to explain the methodology employed and its benefits. After these explanations, families usually welcome the implementation of these methodologies. The remaining trainers who are also teachers declared that they felt the families' support, or at least they did not receive negative feedback. It is noteworthy that all participants expressed that families felt really proud of their children when they saw their children presenting their results in front of an audience.

Co-funded by the Erasmus+ Programme of the European Union

This project has been co-funded by the Erasmus+ programme of the European Union under grant no. 2020-1-ES01-KA201-082102.

4.2 Austria

Here, we summarise the data obtained through five interviews that were conducted on-line and recorded on video.

4.2.1 Sample

We have five Austrian teacher trainers from established Austrian institutions which provide teacher training, one of which is fully on-line. *None of the institutions offer an overall STEAM approach or framework, perhaps because this is not part of the curriculum.* Three offer limited STEAM modules e.g. “How does the ear work”, 3-D printing, augmented reality with knowledge and materials which could be implemented in the classroom. Project based learning and gamification were both mentioned once. One institution plans to offer an on-line workshop course on “Implementing augmented reality in STEM education”. MOODLE and ZOOM and H5P were mentioned by two institutions. One teacher trainer also teaches in a *school in which there is no STEAM collaboration, support or parental involvement.*

4.2.2 Methodologies for delivering STEAM education

Our five Austrian subjects are all experienced in teacher training, aged between 28 and 42, of doctorate level, knowledgeable about STEAM (with one exception) and with related research interests. They have between 4- and 6-years STEAM experience (with one exception: The self-proclaimed non-STEAMer nevertheless provided valuable insights into what STEAM approach/support might be required). The teacher/institution providing purely on-line training, conforming to the same Austrian curricular requirements and accreditation as for the other institutions, also provided valuable insight to the pragmatic requirements of on-line STEAM.

In summary, for the purposes of identifying national differences, the Austrian cultural differences/flavours might be:

- STEAM is not in the curriculum and not assessed therefore there is a lack of perceived benefit to teachers and students. Teachers focus on single subjects and do not have time to address STEAM. However, they all have a second expertise which can be brought into play.

To address this is primarily a support issue so the teacher is not working alone:

- Teachers to work in multidisciplinary, supportive, collaborative groups.
- Address teacher issues head-on at the start with live group meeting
- Project and Problem based approach including teachers' "second subject" (all Austrian teachers are trained in/are expert in two subjects.
- Project and Problem based approach supported by appropriate scaffolding and best practice, proven "plug-and-play" modules and games which can be easily inserted into an integrated STEAM approach
- Mix of physical and on-line working synchronously and asynchronously
- Focus on affective factor for students and teachers (learning that relates to the learner's interests, attitudes, and motivations) and gamification
- Help the teacher take it out into their school

Numbers accompanying the descriptions below refer (where not obvious) to the number of teachers who answered the same. Also bear in mind that *none of the institutions offer an overall STEAM approach or framework. Our subjects are therefore referring primarily to their individual activities.*

What methodology are you applying for delivering STEAM education to secondary school teachers? Responses were:

- Project-based Learning (2) Inquiry-based Learning (1)
- Problem-based Learning used with concrete problems/issues faced by teachers (1)
- Flipped classroom (2)
- Digital and physical learning activities (2)

In addition, added structure/scaffolding/support was suggested by:

- Design-based learning or learning by designing to address the goals of the TPACK model. Designing pedagogical and technological frameworks on how to teach with technology or in technology related subjects (1).
- Synchronous and Asynchronous purely online learning (1)
- Direct instruction, especially if teachers have little/no pre-knowledge (1)

Co-funded by the Erasmus+ Programme of the European Union

This project has been co-funded by the Erasmus+ programme of the European Union under grant no. 2020-1-ES01-KA201-082102.

What subjects are you normally integrating into your courses? Combinations cited were mostly maths and science based:

- Mathematics, Social Sciences, Geography. (1)
- Mathematics, biology, and physics very marginally (1)
- Science and Maths (1)
- Maths, Stats and social sciences. (1)
- Subject independent role to help teachers to use technology in their subject (1)

Interestingly, two opportunities for multi-subject collaboration were identified:

- Austrian teachers are trained in TWO subjects and therefore a group of Maths teachers might well together have the second subject expertise to address rich STEAM.
- One teacher trainer had a subject independent role to help teachers to use technology in their subject/classes. Hence, a technology module such as 3D printing might attract a group of teachers with complementary expertise.

4.2.3 Challenges and solutions

What methodology or approach would you recommend for delivering STEAM education? Why? Similar to above, responses described:

- Problem-based Learning (2) used with
  - Concrete problems/issues faced by teachers (1)
  - Gamification (1)
- Project based and/or inquiry-based learning (2)

The need for structure was reaffirmed by the same teacher trainer:

- Project based learning with Scaffolded design-based learning: guided inquiry or scaffolded design-based learning rather than pure discovery learning or pure experiential learning to get a deep understanding of content to be able to apply the knowledge in new situations.

Also, the purely on-line teacher trainer recommended:

- Online professional development because teachers can participate irrespective of time and place. Gamification should be combined with problem-based learning.

One subject recommended linking pedagogical and psychological perspectives in particular the “Affective” factor. This will recur at various points in the document.

Generally speaking, what are the greatest challenges to effectively teach and implement integrated approaches to STEAM education? Clear challenges posed by the Austrian educational system are:

- STEM/STEAM is not a curricular requirement
- Single subject focus: PTD is usually subject-based. It is hard to convince math teachers that STEM/STEAM is fruitful that by using the approach results in higher students’ motivation and grade. Teachers have their own subjects and, in the curriculum, it is separated instead of combined.
- Meeting the curriculum requirement: how teachers can guarantee that by doing a project they can achieve the curriculum.
- Time: Teachers always complain that they do not have enough time. I said, you would have more time if you do a project together. Integrating the A in STEAM education as teachers mostly state that they have no time for arts in STEM education.
- Assessment: Teachers do not implement STEAM projects because it is not teaching for the exam. Teachers have to deal with ready-made exam questions and they cannot make their questions.
- Student perceived benefit: (Teachers have) to spread an atmosphere of curiosity and open-mindedness so that students do not just focus on fulfilling the minimum for their (single subject) grades.

One subject addressed the Affective (Papert) factor:

- Finding the balance between guidance and openness. The use of content that really helps students and is not just fascinating or so. Combine affect with effective teaching strategies like generative activities.

Please, specifically indicate the best methodologies/approaches to deliver STEAM education and explain their main handicaps or challenges. Already mentioned in detail in responses above, recommendations are:

- Problem-based learning - but has got very much potential to fail: if students have/find no problem or issue to be discovered (or they do not want to find it), teaching and learning does not start (1)
- Project-based learning (1)
- Plug and play resources with integration (1)

What recommendations would you give to overcome the aforementioned challenges for each methodology? These can be grouped as:

- Address teacher issues head on: In an online live meeting teachers' preconceptions regarding STEM education could be tackled and discussed.
- Work in groups: The project should collaborate with other teachers. The biggest problem is they still work alone not in a small group for their projects.
- Start with a familiar subject: that the teachers really know then connect with other subjects.
- Be able to react with different approaches:
    - Different strategies to solve dynamic challenges and to react.
    - Have a plan B (and C and D), have a STEAM subject.
- Game-based learning or gamification: can be used to enrich experience in the online professional development course. Teachers can get badges or need to get some badges to be able to continue the next lesson. Encourage teachers to create their own games and play it together with their peers. The learning environments can be more dynamic and interactive.
- Educational technology support: Most educational technology and instructional design address STEAM subjects. Educational technology focuses on STEM, working together in interdisciplinary.
- Combine synchronous and asynchronous activities in an online professional development course.
- Affective and cognitive sides: Project-based learning can be motivating and make learners learn. A good structure motivates learners and they perform better

compared to the control group. There is a positive correlation between affective and cognitive factors.

What recommendations for pre-service education could help teachers better integrate STEAM subjects? Many recommendations were forthcoming. These can be grouped as:

- Define Scope of Problem and Approach
    - Provide courses on STEM education in teacher education programmes.
    - Organized approach to what we would like to focus on, then to think about how to integrate in teacher training - with willingness of various persons (teacher trainers) to implement this topic).
- Convince teachers of the value of STEAM
    - Demonstrating that it could work - i.e. use it in pre-service education as a teaching approach.
    - Convince either in-service or pre-service teachers that STEAM approach is fruitful
    - They should be confident that students learn so much more with the STEAM approaches. They should believe that students could learn the topics of the curriculum and meet the exam as well.
    - Give teacher evidence-based information on project-based learning
- Collaboration between teachers:
    - Regular meetings are needed but with a sensible schedule for the teachers.
    - Teacher education programmes are in need of promoting cooperation among groups.
    - Instructional design and doing projects with teachers and schools to create an interdisciplinary team.
- Focus on project-based learning on various topics, which can be explored from many different perspectives.
- Mix of online or offline programs.
- Best practice, Practical plug-and-play modules
    - Teachers need practical ways to practice STEAM Education.
    - Best practice examples are needed so teachers get inspired.
- Reach out to schools.
    - School development is important, developing learning culture in schools.

Co-funded by the Erasmus+ Programme of the European Union

This project has been co-funded by the Erasmus+ programme of the European Union under grant no. 2020-1-ES01-KA201-082102.

    - Give teachers the tools to do this and that in their own schools.
- Consider the cognitive, affective, and psychomotor dimension.

What recommendations for in-service or continuing professional development would help to support integrated STEAM education? Recommendations are:

- STEAM approach needs to be introduced to teachers with particular regard on how to integrate among STEM subjects within the curriculum.
    - Teachers need to know the real-world connections, benefits to students about their professional life in the future, and networking thinking such as problem solving and other more problem-based approaches.
    - Highlight the pros and possibilities of teaching STEAM in professional development courses.
- Providing best practices and examples
- Providing teachers with a repository or teaching/learning resources.
- Workshop approach: There could be some workshops for a start (with "ready-made" examples for teachers to implement), a course for in-service teachers, and finally a kind of plan of how to integrate this topic in various lectures.
- Teamwork multidisciplinary:
    - This teamwork is really important. They do not only have together in team, but also outside of their subject. In Austria we have combination of subjects, in secondary level teachers have two subjects. I always ask what is their second topic before the training process. They mostly have math and physic. Sometime have geography or sports. This is really nice when they have other subjects so we can create an interdisciplinary learning.
    - It is good if arts teacher says that math project is wonderful and vice versa. It is really fruitful if teachers can see that they see interdisciplinary between subjects: geography, physics, arts, language, and etc.
- Evidence-based learning materials, e.g. we did a project on AR and computer science, you find it under pcbuild-ar.com, combined with well-designed instructional designs that really help learners learn. Further education and online courses that address these affordances.
- Design-based learning is important to introduce the teachers with 21-century technologies. The best strategy is to give examples. From the TPACK papers

written by Mishra and Koehler, it says that so far teachers training program is just talking. It would be better to do real workshop for their projects.

- Integrate technology to pedagogical perspectives. Augmented reality provided ideas to integrate it. Teach teachers on how they can create good educational learning materials. Convince them if the technology is a good tool for teaching and teach them how to use it.

4.3 Finland

The interviews were held in Finland in 2020 March through online tools (using Zoom) except for one face-to-face interview.

4.3.1 Sample

The Finnish sample included four STEAM teacher trainers and one in-service primary school teacher who also trains other teachers at national and international level. Two of the STEAM trainers are from universities, one is from an educational company that promotes creative education, and one works as a freelance. Four of the interviewees are male and one of them is female. The age of the interviewees ranged from 28 to 64. The years of experience of the STEAM trainers was from 5 to 25. The trainers from universities offer teacher training courses and in-service teacher development programs by implementing STEM- and STEAM-related programmes. The trainer working in the creative education company and the freelance trainer internationally offer STEAM training courses for teachers in primary and secondary schools. Their training courses are based on Finnish educational approaches and on creative educational frameworks. The teacher also offers many STEAM-related content as part of his classroom practice and also promoting STEAM approach for national and international audiences.

4.3.2 Methodologies for delivering STEAM education

The interviewees agreed that they prefer experience-oriented learning and learning-by-doing approaches. They believe that students can integrate subject-based content through applying knowledge in various situations. The trainers are motivated to respond to students' needs with innovative solutions and the methodology. By adding the Arts component to the STEM framework mainly in the format of visual arts and creative

Co-funded by the Erasmus+ Programme of the European Union

This project has been co-funded by the Erasmus+ programme of the European Union under grant no. 2020-1-ES01-KA201-082102.

challenges, the trainers encourage learners to actively participate and apply what they have learnt. The trainers found important to provide first-hand experiences and whole-body experiences and to enhance creativity. One of the trainers said that the essential key concepts are integration, multidisciplinary approach, and co-teaching methods. The approaches in which the interviewees deliver their STEAM education were the following:

- Multidisciplinary learning-related approaches, based on the Finnish Curriculum
- Project-based learning: Finding, designing the rubric for project-based learning is critical. Teachers are usually struggling to give the proper instructions for project-based settings, and they also have challenges in determining the goal of learning processes.
- Phenomenon-based learning: Sometimes it is difficult to understand the concept of what a phenomenon is. The outcomes of learning are also very important. Why it is important to deal with the phenomena instead of the subject? There is often confusion between the concept of the phenomenon itself and the reason why you need to conduct a learning project dealing with the phenomena.
- Collaborative learning
- Creative pedagogy, including Finnish STEM and STEAM frameworks for primary and secondary level: For some teachers, it is not easy to imagine how they can use creativity in the subject they are teaching. They think to be creative teachers, they need to have some specific, artistic talents (drawing, music, handicrafts, etc.).
- Pedagogical leadership in integrated teaching and learning
- Inquiry-based learning and problem solving: Most of the time, teachers are not focused on what and why they need to do to establish the inquiry process and they are also not sure about how to do it.
- Working not only in-school but also in out-of-school environments

Notably, all of the trainers and the teacher emphasised the importance of project-based learning. One of the interviewees recommended project-based learning and phenomenon-based learning in a two-steps approach. Step 1 is for providing the basics of project-based learning. Teachers first need to understand how to implement a topic in a project-based framework. Then, Step 2 is the establishment of phenomenon-based learning, which gives a holistic view to integrating the subjects.

This project has been co-funded by the Erasmus+ programme of the European Union under grant no. 2020-1-ES01-KA201-082102.

4.3.3 Challenges and solutions

The Finnish teachers pointed out some challenges and identified a few solutions. The challenges and solutions are summarised based on these themes: school culture, resources, and training opportunities.

School culture

One of the major challenges that the interviews mentioned is connected to the Finnish school culture. Since teachers' autonomy is highly regarded in Finland, teachers may tend to work independently or separately. With this kind of mindset, it is sometimes difficult for some teachers to understand the integration of subjects and challenging for them to plan integrated processes because it requires close collaboration with other teachers. One trainer pointed out that teachers are used to teach and learn with a mindset of a compartmented education system, and it is hard to change them. For example, there can be physicists who are not happy when they get to know that visual arts are also included in the teaching of physics. One trainer also said that the school culture is often too conservative to change. It is difficult for the future teachers to imagine that they can tell the older teachers that they would like to do things in a different way.

The solutions to overcome the issues related to the school culture suggested by the interviewees were related to leadership and shared vision. First, school leaders including principals need to acknowledge collaborative endeavours among educational staff to realise STEAM education that develops students' transversal competence. The interviewed teacher confirmed that the importance of teachers' activities is appreciated by the school board and the principal. This appreciation encourages him to progress with STEAM education and training. Although teachers' autonomy is highly respected in Finnish schools, the interviewees agree that a strong vision needs to be shared among the teachers and other educational staff in the school. While schools need a structured curriculum and connections among subjects, teachers' mind needs to be flexible and connected through the vision. One trainer mentioned that if something goes off-track or "wrong", they need to respond to it with flexibility. Another trainer claimed that the best part of STEAM projects is starting from vague phases that require a lot of negotiation and discussion, and a shared goal. Since the trainers believe there are many ways to realise

This project has been co-funded by the Erasmus+ programme of the European Union under grant no. 2020-1-ES01-KA201-082102.

STEAM teaching, they emphasised careful project planning although it then involves more people, more organisation, and more resources.

Resources

The interviewees mentioned human and time resource issues. First, every trainer argued that to realise STEAM education, it is good to have a cooperation with another teacher who observes and provides support. One trainer said that this is because teachers are overwhelmed by daily tasks, and they are under pressure for any extra efforts to be done. Peer support can be not only physical but also mental support. Another trainer argued that there needs to be room for some kind of professional assistance that is very important to learn from each other. He said that after deepened own subject-based skills, teachers need to put effort to get to know each other's subjects. Therefore, peer support can also be a place for learning.

A solution to fill the knowledge gap between teachers is to have a toolbox or platform where previous practices are stored and shared. Another solution suggested by a trainer is to make the most of informal learning resources that the teacher is interested in. Informal learning resources can be web-based and cultural opportunities, such as visits in museums, science centres, and events. Learning from peer groups, learning from other teachers, learning from the pupils, social learning in various groups can help to achieve a wider perspective on what is needed. He even mentioned that involving hobbies and non-subject-based interests can help a lot.

Second, the interviewees agreed that more time resource is needed. Nowadays, Finnish teachers are too busy while they had more time in the past to discuss. Usually, teachers have only 15 minutes for a coffee break in-between the classes and it is too short to plan multidisciplinary learning. It depends on the individual, how a teacher gets along with another teacher. They share ideas, however, they are not so much active in collaborative teaching because of the Finnish teacher culture as indicated above. Thus, teachers need time to discuss what are the activities about and what are the expectations in STEAM education.

One important solution suggested by the interviewed teacher is to set a fixed time to collaborate among teachers. In his school, teachers implement Multidisciplinary Weeks in the school. In these weeks, the teachers take collaborative discussions where their ideas cross the subject borders. They organise various educational programs for the students and try to involve different groups and experts in the school activities. Another similar example also suggests setting a special week dedicated to multidisciplinary learning before the school year starts. The school teachers and staff design the whole year's program on 5-10 topics.

Training opportunity

The interviewees pointed out mostly the lack of the training opportunities. When trainers try to integrate, e.g., primary school teachers, who know more about the pedagogy, and subject teachers, who know more about the subject, they may not know how to integrate their expertise and knowledge. That is, sometimes it is difficult to add the overall knowledge to different knowledge areas. One trainer argued that it has to be part of their pedagogical planning process. Teachers need to consider how to use the integrated approach in connection with curriculum planning. Thus, teachers would need more experience with the formats and approaches that encourage their collaboration.

Some of the trainers emphasized the importance of pre- and in-service training that ensures STEAM education. They argued that although training needs to be designed to start very simply for pre-service or early-stage teachers, integrated teaching approaches are needed already at the teaching practicum level. Teacher students should try it already in their practical courses. Teacher students need not only conceptual clarity, but they need to be able to try the implementations in practice as part of their training. One trainer discussed the importance of finding their teaching style and reflect on their own capabilities and strength even at the teacher education level. This is because if everybody receives the same training, it can become challenging to experience how to implement their own style. For example, if a teacher is good at sports and if a teacher would like to use it in an overall integration, they need to become confident in how to integrate sports with other subjects such as math. They need to be aware that these combinations are possible. By implementing STEAM education by themselves, teachers can try to start applying it.

Another trainer mentioned that teachers need to receive proper training for collaborative teaching or how to collaborate with other teachers. One trainer suggested, for example, a co-teaching course for preparations to ensure shared leadership. Since teachers are leaders who lead learning in the school, some interviewed trainers put emphasis on shared leadership, and they should have a course for practicing project learning itself.

4.4 Greece

The interviews took place in Athens/Greece, through teleconference (using MS Teams, Zoom and Cisco Webex Meetings), from 2.4.2021 to 2.16.2021.

4.4.1 Sample

There were seven (7) interviewees:

1. Six of them are trainers on STEAM education approach.
2. Two of the trainers are School teachers and educators of in-service teachers.
3. One of the trainers is an Academic teacher in NKUA and, moreover answered the questions from the part of the institution carrying out and offering training for teachers.
4. There was also one interview taken from a school principal, not a trainer in STEAM. The school constitutes an institution carrying out trainings for in-service and pre-service teachers around STEAM approach in teaching.

The interviewers were members of the NKUA project team. For more details around the trainers' interviews, the following table is available.

Role / Position	**Institution**	**Years of experience**
Conducts courses addressed to pre/in-service teachers around designing stem activities/games	NKUA	2
Prof./ Under/post-graduate, PhD, in-service teacher educator	NKUA	27
Teacher and teachers' trainer in educational robotics	NKUA	2
Designer of STEAM educational programs	NKUA / "STEM Education"	1
Teacher trainer of in-service mathematics' teachers in the integration of digital tools into teaching	Greek Ministry of Education	9
Trainer of pre/in-service schoolteachers around the use of digital tools, STEM approach and instructional design.	NKUA / 2nd Model JH-school of Athens	8

Three of the interviewees were experienced schoolteachers and an academic teacher with many years of experience in teacher training. There were also three trainers with "solid"

Co-funded by the Erasmus+ Programme of the European Union

This project has been co-funded by the Erasmus+ programme of the European Union under grant no. 2020-1-ES01-KA201-082102.

theoretical background (Masters in Education, PhD), but not much experience as teachers in the classroom. So, it seems that on the one hand, teacher trainers are members of the educational community, enjoying the acceptance of the educational community, while on the other hand teacher trainers with less experience are getting involved in training design.

4.4.2 Subjects integrated and methodology applied in classroom

The subjects that the interviewees are normally integrating in their courses were:

- Mathematics
- Science
- Humanities and technology
- Mathematical in other subjects like Mathematics, Physics, Geography, Programming and computational thinking, Engineering and Humanities
- Technology
- Programming
- Engineering
- Physics
- Art
- Solving real-life problems
- Study of phenomena
- Socio-scientific issues

Their most common teaching methodology applied in classroom were:

- Inquiry-based learning
- Project-based learning
- Problem solving
- Game-based learning
- Constructionist approach
- Constructionist-based learning (activities involving artistic construction of digital artifacts)
- Collaborative learning
- Design thinking

Co-funded by the Erasmus+ Programme of the European Union

This project has been co-funded by the Erasmus+ programme of the European Union under grant no. 2020-1-ES01-KA201-082102.

4.4.3 Challenges

According to the interviewees, we have gathered recommendations around the methodology to be used for delivering STEAM education.

For teachers

- Constructionist approach: Teacher takes the role of STEAM centered artifacts, activities and games designer. Being involved in the phase of design, which includes exchange and evaluation of practices among teachers, they realize the connection of subject in STEAM approach. They are also engaged in collaboration, discussion, and discourse, and “boundary crossing” since they cross the boundaries of different fields of expertise. When a teacher designs an activity, he/she owns this activity, in the sense that he/she can adapt it to his/her teaching goals, to his/her students’ ambitions in order to motivate them and to the level of freedom/creativity of his/her willing. Game based learning and problem solving learning are also methodologies rich in educational opportunities that support interdisciplinary approaches, where mathematics, science and technology can be creatively combined in a meaningful context; in order to solve a problem or play/design a game.
- Moreover, through problem solving trainees are involved in naturally.
- See teacher as recourse and activity designer, individually and in communities of practice and communities of interests.
- Enhanced Project Based Learning: Teachers experience the way STEAM learning happens. When simulating an educational activity, and giving the time to reflect on the experience, teachers understand what are possible problems that can occur or think about effective strategies they can apply to stimulate their students interest and learning.

For students/pupils

- Create situations where students design construct tinker with and talk about artifacts which they find useful, relevant and enjoyable, design such artifacts to get them started by taking care to embed powerful ideas e.g. of mathematics so that they identify and put them to use. Build on their engagement, ownership, emotional involvement, discourse. This way we can support students to adopt lifelong habits of mind and dispositions towards inquiry, mathematical thinking, rigor, logic.

- Enhanced Project Based Learning: Students experience the way STEAM learning happens.
- Problem solving, project Because trainees are involved in.
- Inquiry Based Learning implemented on Integrated STEM Approach, with regards to a Soft Skills' framework, like 4Cs, or Reference Framework of Competences for Democratic Culture, developed for the Council of Europe. This is an applied framework for STEAM instructional design and observation of teaching, in a procedure that includes iteration and reflection between cycles of learning courses.

We have also tracked challenges to effectively implement integrated approaches to STEAM education.

- Activity and Resource design approaches are very beneficial for delivering STEAM education to teachers. They allow teachers to express their ideas, develop ownership of STEAM artifacts, understand interconnections of STEAM fields in practice, and develop their profession. Artifacts and activity designs also become boundary objects for teacher community discourse about pedagogy and cultivate clear ways of communicating new and indispensable roles for teachers in human interaction teaching. This kind of education is challenging to teachers, questions their formed beliefs about educational paradigm and process, requires them to enhance their design and production practice, requires them to learn the technicalities of new tools and to put new pedagogical methods such as project work and design thinking into practice.
- A big challenge is for teachers to leave their "comfort zone" and their field of expertise and implement multidisciplinary approaches.
- The push towards a paradigm shift needs to gather strength and continuity, avoid the educational innovation pendulum. The shift towards meaning-making, inquiry, discourse, life-long learning disposition and habits of mind.
- Make time in schooling for student engagement. Reduce 'curriculum' and exam crunching time by lowering the stakes and giving much more time for young people to make decisions about their lives.

This project has been co-funded by the Erasmus+ programme of the European Union under grant no. 2020-1-ES01-KA201-082102.

- The school curriculum is mostly based on diverse disciplines so it is challenging to overcome barriers of time and content, in order to implement Steam approached in suitable subjects.
- A teacher who is trained to be a STEAM trainer and has the background of a mathematician needs different guidance from someone who has an engineering or Arts background.
- Another challenge is to naturally integrate real-life problems involving diverse disciplines to STEAM approaches.
- Adopt project-based learning approach to give the chance to the educators to exchange knowledge and ideas to integrate in their classes STEAM subjects. This way they reflect on the challenges they faced and think about ways to turn these challenges into opportunities for STEAM learning.
- Inquiry-based learning approach could be used for designing the task to be addressed to students. To avoid turning investigation to traditional teaching of a subject, we should describe the learning activity in detail before teaching, and to observe teaching and learning (using a certain tool for observation. The procedure of describing the learning activity should be done in parallel with designing the task. The learning activity could be described in terms of outcomes based on a certain model. Some of them could be expressed using a version of Bloom's taxonomy (Wilson's or Grass's taxonomy) or another theoretical view, like Harvard's Project Zero's Thinking Routines Toolbox (http://www.pz.harvard.edu/thinking-routines), to describe students' activity in terms of outcomes. This way, the description of learning outcomes and the design of the tasks, are informing one another.
- Enabling constructionist approach, solving-problem and game-based learning approaches: The main challenge of these approaches is for teachers to overcome their attachment to their own discipline and to traditional tasks and be able to create a constructionist activity of their own; an activity which will be able to creative engage students to harmonically integrate different disciplines to achieve a specific goal (play/design a game, solve a problem, create a beautiful artifact). So, the main challenge is for teachers to understand the general educational value of these approaches in order to implement them effectively.

This project has been co-funded by the Erasmus+ programme of the European Union under grant no. 2020-1-ES01-KA201-082102.

- Prove contexts giving the opportunity and time for teacher to engage in the practice of discursive design, reify and highlight their productions and descriptions of their own practice, use social media to champion best ideas and highlight the important issues.

1.1.1 Obstacles and recommendations to overcome them

In the table below, you can see obstacles to teach STEAM approach, and recommendations to overcome them, with regards to interviewees answers.

Obstacle	Recommendation
Curriculum and systemic barriers Obstacles related to disciplines, or exams, and the way schools work.	**For students' engagement** Make time in schooling for student engagement. Reduce 'curriculum' and exam crunching time by lowering the stakes and giving much more time for young people to make decisions about their lives. **For teachers' engagement** Prove contexts giving the opportunity and time for teacher to engage in the practice of discursive design, reify and highlight their productions and descriptions of their own practice, use social media to champion best ideas and highlight the important issues. Also get small groups of diverse teachers to co-design. Get down to the detail of what transdisciplinarity means and how designs can be made to serve two or more silo domains equivalently (i.e. avoid activities using maths to simply serve the understanding of some physics and vice versa etc).
Professional retrenchment Teachers are strongly attached to their own discipline and are not open enough to interdisciplinary approaches; especially ones that involve arts. They often have troubles/objections/show resistance in widening their teaching goals further than the school curriculum goals. E.g., it is difficult for math teachers to combine mathematics with physics and programming in a meaningful way.	They need the appropriate context and technological tools to achieve this integration. Teachers who are being trained in STEAM approaches need a more structured guidance on how to design and implement the lesson and combine all the domains of STEAM.
A threat that the aforementioned methodologies to integrate STEAM might be of small effect. Three typical issues to be aware of are: ● To involve more than one subject in instructional design around STEAM. ● Teachers are not familiar with these methodological approaches.	There is a need for training and supporting resources such as guidelines, templates, and frameworks for teachers. There is also a need for involving opensource digital media to overcome the lack of equipment. To provide teachers with best practices of STEAM activities already implemented in the field with students showing how it was done and what students learned. Engage teachers in

• The lack of the necessary equipment in schools for supporting these approaches in practice (e.g. robotic kits, computers etc).	collaborating activities with other teachers to exchange experiences on STEAM education or from their fields of expertise. Playing educational games or solving (realistic) problems can be approached by teachers in 2 different ways: By participating and adapting the role of a student to engage and by designing an activity of their own based on given templates and guidelines. In this way, teachers can get a clear idea on how to design and implement a STEAM activity and hopefully appreciate its educational value.
The twist from investigation during lesson, to a traditional teaching experience.	Detailed and articulated description of learning outcomes, by the teachers themselves, connected to the design of learning tasks and activity. Using a tool to observe teaching, with which the teacher can take control of facilitating students' inquiry, to help them take part in practices like design, engineering thinking, testing, etc. Activities of reflection on the learning strategies used could be important. Open or structured discussions on activities teachers experienced lead to conclusions about what could or could not be a good teaching practice concerning both students' motivation and learning outcomes.
Issues related to the lack of professional development of pre-service teachers.	Workshops and hands-on activities on how teachers can design their courses for STEAM. Training sessions with focus on STEAM education. Projects with teachers from different STEAM fields working together. Provide more opportunity for the development of teaching and design craft, give concrete advice how to generate time for STEM within silo schooling, build a professional identity for sustainable innovation. It might be beneficial if teachers from different disciplines (e.g. mathematics and physics) collaborate in order to design an interdisciplinary educational project.
Issues related to the lack of continuous professional development of in-service teachers.	Online communities for in-service teachers to exchange ideas or experience on STEAM education. Frequent training of in-service teachers on new technologies and approaches for STEAM education. Equip schools with necessary equipment to support STEAM education (robotic kits, computers, labs). Provide opportunity for in-service professional development as part of the teaching profession for the length of each career, sustainably.

Co-funded by the Erasmus+ Programme of the European Union

This project has been co-funded by the Erasmus+ programme of the European Union under grant no. 2020-1-ES01-KA201-082102.

	Build sustainable diverse communities of interest. Champion innovative practices and designs. Provide infrastructure making tools and designs available to teachers. Could be part of an online community for openly sharing STEAM experiences and ideas (in Greece there are some facebook pages where some teachers do that, but in a small scale). The crucial role of schools supporting activities, by including project-based lessons to their program and provide the appropriate technological equipment. The content and the best practices used in in-service teacher training should be showed up, and documented as effective in everyday school practice. It is also crucial to induce teacher educators to adopt all the above. The in-service teacher educator should be accepted as a professional, by the trainees, since they would be likely to pass judgement against the usefulness of STEAM approach. A handy guideline list constituted of "tips", examples and practices to interweave curriculum with STEAM learning goals, provided to the trainees.
About professional teachers' development as a whole	Get small groups of diverse teachers to co-design. Get down to the detail of what transdisciplinarity means and how designs can be made to serve two or more silo domains equivalently (i.e. avoid activities using maths to simply serve the understanding of some physics and vice versa etc).

4.4.4 Issues related to everyday school practice and in-service teacher training in schools

Focusing on the trainers that are schoolteachers as well, we had the following feedback.

Recommendations for pre-service education that could help teachers better integrate STEAM subjects.

- Find tasks around socio-scientific problems.
- Realize that Steam is about processes and introduction into practices, not only knowledge.
- Design to engage students into practices.
- Write down clear and articulated learning outcomes.

Co-funded by the Erasmus+ Programme of the European Union

This project has been co-funded by the Erasmus+ programme of the European Union under grant no. 2020-1-ES01-KA201-082102.

- Observe and reflect.
- Use examples to make the integration of STEAM methods in everyday school practice clear. It should be used examples from diverse disciplines.

Recommendations for in-service or continuing professional development that would support integrated STEM education.

The recommendations are the same as above, plus, suggesting to the trainees ways to interweave curriculum with STEM centred learning goals. The best practices mentioned in the training should be well-documented since the participants in an in-service training course might be more likely to express disbelief.

About the collaboration with other teachers in school for implementing STEAM activities.

The collaboration varies from critical friendly observation with STEAM approach to their contribution in the design of a task with regards to their scientific expertise.

About the support received from school to effectively implement STEAM in classroom.

There are different types and diverse extend of support:

- Program shifting, in order to have 2 or 3 hours available for a class
- Equipment support, like using PC lab.
- Sometimes activities are running during the weekend, and the school administrations helps so that the school to be open.
- Sometimes it is difficult for the school to support. Not all schools are fostering such activities.

About the response from the students' families to the STEAM approach.

In many cases they are usually interested in this kind of activities. Their family-schedule often takes under consideration activities that take place out of the regular school program, for the children to have the chance to be part of.

They are not anxious about their children performance in STEAM lessons. They mostly ask about more classical subjects like Mathematics or Language.

Co-funded by the Erasmus+ Programme of the European Union

This project has been co-funded by the Erasmus+ programme of the European Union under grant no. 2020-1-ES01-KA201-082102.

About the teachers' motivation to get involved in STEAM lessons/classes for the students.

Nowadays' school needs, as they are often described in teaching guidelines, are related to processes, practices, etc. These learning goals are effectively supported by STEM/STEAM approach. Nevertheless, the STEAM driven tasks are motivating for students, as well.

Moreover, there is personal interest in instructional design focused on methods like STEM/STEAM, that put the basis for moving from the content to the design around learning goals, like soft skills, etc.

4.5 Hungary

The interviews were held in Hungary in 2021 February through online tools (using Zoom) due to the uncertain health conditions.

4.5.1 Sample

There are four interviews in Hungary with in-service primary and secondary school teachers. Three of the STEAM teachers are working at universities/research institutions and one has wide-range of experience in international educational working environment and work as a trainer for current and future school principals. Three of the interviewees are females and one of them is male representing the over-female professional field in Hungary. The age of the interviewees is over 50 representing the aging teacher society in Hungary. The years of experience of the STEAM trainers was from 2 to 5. The teachers offer many STEAM-related content as part of their classroom practice and also promoting STEAM approach for national and international audiences.

4.5.2 Methodologies for delivering STEAM education

The interviewees agreed that Project-Based Learning, Problem-Based Learning and Inquiry Learning are all useful strategies. The teacher should discover and experiment with the methods best suit that specific teacher, building on his/her own experience and feedback from students. They find limited use of flipped classroom techniques and gamification that they use but wouldn't build on them as main strategies. One of the teachers emphasised that discovery learning techniques work best combined with

Co-funded by the Erasmus+ Programme of the European Union
This project has been co-funded by the Erasmus+ programme of the European Union under grant no. 2020-1-ES01-KA201-082102.

collaborative work and metacognitive (reflective learning) strategies. Some of the opinions stressed that not the methodology is the main problem but the systemic environment of education. Required standard outcomes influence the process of teaching so much that it governs teachers' work apart from STEAM approach. Other main findings that the teachers deliver STEAM approach in their education were the following:

- Inquiry-based learning is the most important approach they use. Students are required to learn independently and if they lack skills in it, IBL remain ineffective.
- Advantage of IBL is that it helps students to face misconceptions and integrate new knowledge into their structure of thinking.
- Problem-based learning is found to be the best approach to real-life problems in teaching. Challenge is that the amount of available teaching resources is strongly limited.
- Challenge is that the teacher has to learn much more than she/he is ever going to use in teaching.
- Hands-on, minds-on and research-based methodology**.** They both are based on real-life problems. They cannot see any handicaps apart from being time demanding.
- As STEAM education is still in an experimental phase, I would apply a multistep approach to the school. I would start with a step depending on existing experience, competencies, available resources and teachers' period on STEAM education. Students should be able to routinely work in small groups, plan ahead, do independent measurements and in general get used to the idea that they don't only understand, learn and apply new content but there always is the "why" question to answer. These are basic skills for discovery learning or inquiry learning from the students' part that are not always evidently present and may take several months to learn. STEAM education on the other hand would require close collaboration among teachers of multiple subjects and be able to find the time and content frame for doing so.

Co-funded by the Erasmus+ Programme of the European Union

This project has been co-funded by the Erasmus+ programme of the European Union under grant no. 2020-1-ES01-KA201-082102.

4.5.3 Challenges and solutions

Traditionally, Hungarian education is subject-oriented, thus no strong tradition for inter- or transdisciplinarity. So, at the macro (national) and micro (school) level fragmented subjects, mainly Chemistry and Physics represent Science teaching and learning at the content regulation system, especially National Core Curriculum and school educational program and local curriculum. But from 1985 (first "autonomy" Education Act) there are more and more innovative programs, which try to develop more inter- and transdisciplinary approach at this field. From 1995 (first National Core Curriculum) the integrated fields of literacy, e.g. Man and Nature can demonstrate this new approach, but on the base of the implementation research, schools cannot handle this flexibility, inter- and transdisciplinarity and stay the subject-oriented local curriculum.

At the output system, the final mature exam at the end of the secondary school (16 then 18-year-old students) is based on the above-mentioned subject-oriented system, thus after 1995 (first new National Core Curriculum) there is strong incoherency between input and output. The system of initial teacher training and in-service training is traditionally subject-oriented, so the teaching and learning methodology stays at the same traditional subject-and content-based approach. Basically, on the base of the interviews, STEAM education is on the toddler's shoes in Hungary with two-face phenomena. Firstly, there are more and more innovations at this field with project-, problem- and inquiry-based learning turning to stronger inter- and transdisciplinarity. Secondly, especially Chemistry and Physics are struggling with students' motivation and lack of new teachers.

Careful planning of teaching and doing project is time demanding and essential in effective teaching. Students need time to develop skills in autonomous learning techniques and staying active without the teacher's supervision. One of the teachers said that her own skills and knowledge in different subjects is the greatest challenge. She has to regularly study and push the border of her subject knowledge in those subjects she is not specialized in. Social and family acceptance of STEAM learning is low so students many times get the "why would you learn this way" questions out of the school.

Co-funded by the Erasmus+ Programme of the European Union

This project has been co-funded by the Erasmus+ programme of the European Union under grant no. 2020-1-ES01-KA201-082102.

It is hard to synchronise, implement and institutionalize STEAM approach and content with the national curriculum and outcome expectations. Challenge is that the teacher has to learn much more than she/he is ever going to use in teaching, as lack of time is an important factor both in teaching hours and preparation. The primary difficulty is to find or create resources that not only offer input for a few lessons but can be consistently used throughout the entire academic year. Because of the large amount of creative effort, STEAM in this early phase is time demanding from the part of the teacher. Not directly connected to STEAM teaching, however positive school and classroom climate is a great contributor to students accepting new ways of learning.

4.5.4 Recommendations and issues related to everyday school practice and in-service teacher training in schools

One of the main findings is that students haven't even heard about STEAM education so introduction to what it is and how it's done would be beneficial. Providing teachers with a repository or teaching/learning resources should be implemented. It is necessary to develop initial and in-service training programs, which are coherent with STEAM education approach from methodological and integrated curricular point as well. At the school level, it is important to strengthen networking in order to change traditional school culture, which is based on the "this is my subject, this is my castle" principle. Networking has two levels. At the micro level, inside the school, giving the opportunities to collaborations for professional learning communities. At the macro level, it is important to strengthen cooperation among the different schools.

There should be place for creative work during which the future teacher experiments with STEAM methods and interdisciplinary approach. As an integrated part of teacher, training it should be a target for students to regularly use STEAM methods in their in-service training. For teachers it is the continues "trial and error", learning from experimenting with different teaching methods and strategies. Teachers usually monitor students' involvement and keep on doing what really involves them but drop those techniques that do not result in active participation from students.

It is also important to provide teachers with resources as well as to allocate time to plan and evaluate STEAM education and progress of the classes. Another issue is that a crucial part of the national curriculum in which there has been a relevant reduction of the number of STEAM hours of lessons. This became an important challenge in teaching steam subjects. There should be knowledge sharing events for teacher in conferences and other platforms.

Supports from the respective schools

Generally, teachers from secondary and primary schools do not receive supports to introduce STEAM teaching and STEAM approach in their practice. One of the teachers said that she receives supports from her research institute where she works every day beside her school practice. Another teacher stated that she gets support in forms of time dedicated to CPD events. Therefore, it would be welcome if schools and other actors in the field of education were required to give support for teachers who are innovative and want to introduce innovative approach and elements in their educational practice.

Overall, we set out that teachers are reluctant to introduce new methodologies in their teaching practice due to the lack of motivation. However, many of them are ready to innovate sg. in their methodology because they find traditional approaches not motivating students enough and not being linked to their real life. STEAM can bring real problems closer to students and involve them into learning better.

5 SELECTING METHODOLOGIES FOR TRAINING TEACHERS IN STEAM

The methodologies identified in Section 3 could be incorporated into an integrated STEAM framework. In fact, previous experiences in the framework of European projects have been already identified. Considering strengths and weaknesses of the above methodologies and issues to be overcome, we can also identify best requirements for training teachers:

An integrated STEAM approach is necessary with course content featuring a balance of mixed subjects over the course of the programme. Project-based Learning and Collaborative Problem Solving provides an overall framework for addressing challenging open-ended technological and/or societal issues. The inquiry-based and design-based learning, dimensions of PBL, also are effective for promoting strategy solutions and problem solving.

Games, gaming and user centred design are important contributors to a positive user experience as is the peer-to-peer collaboration of users (teachers' trainers, teachers or students) and assessment. Community network and learning is important support for individual learning and takes place implicitly in the above-described approach. Citizen Science with co-creation process is a potentially valuable tool for this; however, its expert application may be too complicated and should be initially offered an optional tutorial.

In the light of the above, the best way to train teachers in integrated context education is to provide them with knowledge and skills on the five dimensions of PBL. This will allow qualify teachers, although this will require long periods of training on project design and implementations. The other option will train teachers on only some of the five dimensions in shorter practices.

6 A REFINED TRANSCULTURAL PROFESSIONAL DEVELOPMENT FRAMEWORK

This section explains how we developed the transcultural STEAM professional development (PD) programme for in-service and pre-service secondary education teachers. The programme aims to train teachers on the *design*, *implementation*, and *evaluation* of STEAM activities within the curricular objectives of the five educational systems participating in this project. The PD program has been tested with in-service and pre-service teachers from Spain, Austria, Finland, Greece and Hungary.

6.1 First framework design

The Transcultural STEAM framework emerged from a combination of the theoretical information obtained from the literature, from the data gathered from trainers and teachers, and from an iterative and experimental phase of programme design, testing and refinement. After thoroughly reviewing the STEAM literature and related methodologies, the partners jointly developed the first STEAM professional development (PD)

Co-funded by the Erasmus+ Programme of the European Union

This project has been co-funded by the Erasmus+ programme of the European Union under grant no. 2020-1-ES01-KA201-082102.

programme, which includes three main dimensions: theoretical, experimental, and project design (Image 1).

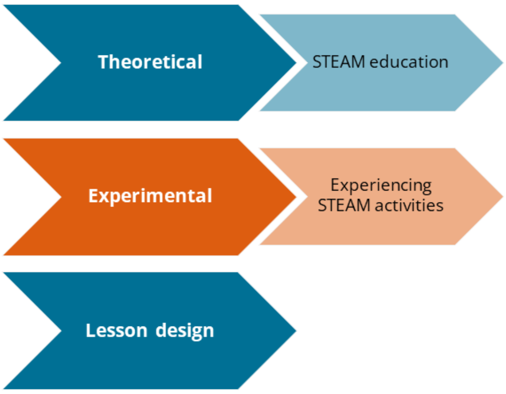

Image 1: First framework attempt

This first training attempt was of about 8 hours of work with teachers. In the theoretical dimension, participants were introduced to STEAM Education: what is STEM and STEAM Education? Advantages/disadvantages). In the second dimension (experimental), the participants were requested to reproduce a STEAM activity, as they were their own students. We aimed to get participants to experience the difficulties and fears that their students could encounter when reproducing a similar activity. In the third dimension, the participants were asked to design a STEAM activity following the guidelines in the table below. These guidelines resulted in the following template for designing activities that is available on the project website in two languages: https://www.steamteach.unican.es/template/

1. **Describing students for whom the STEAM activities are going to be developed** (e.g., 14-year-old-students) 2. **Providing the phenomenological context of the activity** (e.g., any real context) 3. **Content/procedures that the activities aim to cover** (e.g., any content related to secondary school education. Establishing content equivalence among the five countries)

4. **Competencies/skills that the activities aim to cover** (agreeing on some STEAM competencies to be developed. In maths, we can for example aim: reasoning, conjecturing, proving, generalising, and so on)
5. **Objective of the activity** (e.g., introducing new knowledge or fixing existing knowledge)
6. **Role of the Teacher**
7. **Elaboration of the activity**
8. **Instruction** (e.g., motivation of the problem, beginning with examples, beginning with the theory, working in groups, number of sessions)
9. **Evaluation** (e.g., using a rubric to evaluate students' knowledge, skills, and competencies)
10. **Verifying the adequacy of the activity before the implementation** (e.g., using for example a rubric)
11. **Implementation and evaluation of the activities** (here we have another framework related to the instruction, etc. to be considered in the following IOs)

After several implementations and evaluations of this framework with teachers from different countries and disciplines, several refinements were applied. The evaluation includes two main parts: (1) analysing the strengths and weakness of the courses according to participants' satisfaction using questionnaires, interviews and observations, and (2) analysing the suitability of the activities designed by the participants against the guidelines provided, using rubrics and a qualitative approach.

6.2 Second framework design

As Image 2 shows, the second framework incorporated a new dimension (implementation). After being asked to design a project, the teachers were asked to implement it with their students and present their outcomes. The theoretical session was amended, including specific information about project based-learning and its five dimensions: content integration, problem-based learning, inquiry-based learning, design-based learning, and collaborative learning (Thibaut et al., 2018). The experimental session was also refined incorporating, pedagogical training in technological resources such as GeoGebra and Tracker. In addition, we added a session for exhibiting good practices and describing teacher experiences. These incorporations turned out to be useful for designing and implementing STEAM projects.

Co-funded by the Erasmus+ Programme of the European Union

This project has been co-funded by the Erasmus+ programme of the European Union under grant no. 2020-1-ES01-KA201-082102.

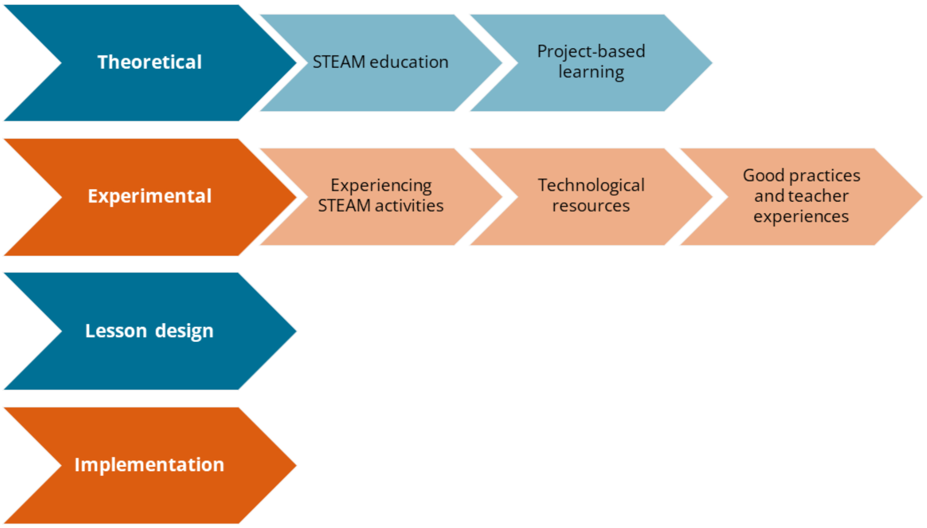

Image 2: Second framework attempt

After evaluating this second framework, we noted that both pre-service and in-service teachers required sustained support during the four phases: theoretical, experimental, project design, and implementation.

6.3 Third framework design

As a result of evaluating the second framework in the participant countries, we incorporated the support of STEAM trainers and professionals (Image 3). The support, especially during the design and implementation phases, helps teachers significantly gain knowledge and skills on the development of STEAM projects and also confidence.

Co-funded by the Erasmus+ Programme of the European Union

This project has been co-funded by the Erasmus+ programme of the European Union under grant no. 2020-1-ES01-KA201-082102.

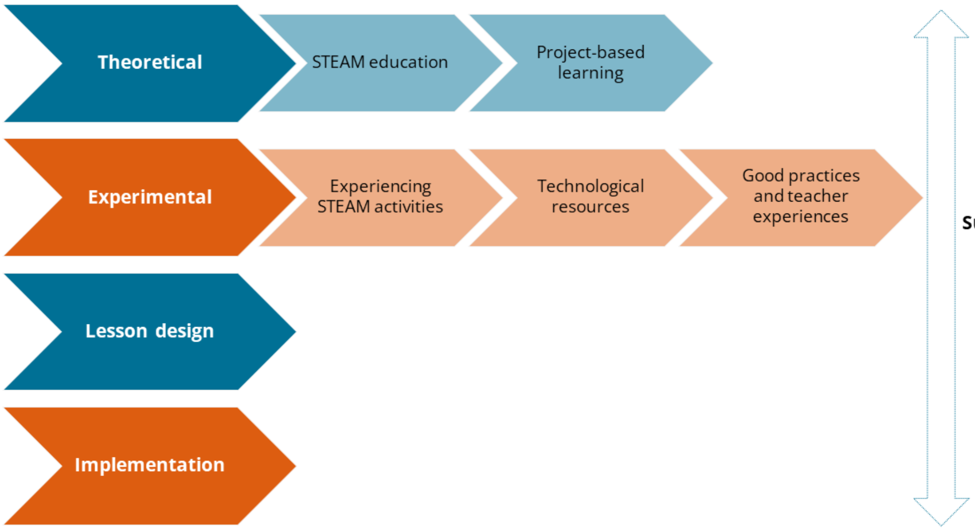

Image 3: Third framework attempt

This cross-cultural framework is the result of several interactions. The outcomes suggested that it is a suitable tool for training teachers in Spain, Austria, Finland, Greece and Hungary.

7 CONCLUSIONS

This intellectual output includes a comprehensive documentary analysis of the State of the Art concerning STEAM Teacher Training. This analysis served as the foundation for the development of a Transcultural Professional Development Framework. This framework aimed to encompass diverse cultural perspectives and enhance the effectiveness of teacher training in the STEAM field. In this review, we have also identified the most effective methodologies for implementing STEAM Education including our own expertise, and the best ways to train teachers in such methodologies. Considering trainers' interviews, the STEAMTeach consortium agreed on STEAM project-based learning for training teachers (IO2) and implementing STEAM activities in regular lessons (IO3).

After selecting the learning methodology, we designed a draft of the STEAMTeach professional development programme comprising three dimensions: theoretical training, experimental training, lesson design and implementation. After successive refinement processes derived from the execution of training programmes (IO2) and the implementation of activities in regular lessons (IO3), the STEAMTeach framework evolved toward a more complex structure, incorporating four dimensions —theoretical training, experimental training, lesson design and implementation in regular lessons— and a transversal one —support. This structure, which is not common, is aligned with Chai (2019) and Diego-Mantecón et al. (2022), which advocate for complex STEAM professional development programmes for effective teacher growth.

Additional details regarding the practical utilization of the STEAMTeach framework to execute the planned cross-cultural developmental program within each partner country are elaborated upon in the subsequent Intellectual Output (IO2).

REFERENCES

Abt, C. C. (1970). *Serious Games*. Viking.

Akgun, O. E. (2013). Technology in STEM project-based learning. In R. M. Capraro, M. M. Capraro & J. R. Morgan (Eds.), *STEM project-based learning. An Integrated Science, Technology, Engineering, and Mathematics (STEM) Approach* (pp. 65-75). Sense Publishers. http://dx.doi.org/10.1007/978-94-6209-143-6

Angeles, G. de los. (2016). Scaffolding Role-Playing: An Analysis of Interactions with Non Role-players of All Ages. *International Journal of Role-Playing*, *6*, 20-26.

Association of Flipped Learning Network. (2014). What is flipped learning? http://fln.schoolwires.net//site/Default.aspx?PageID=92

Basadur,M., Pringle, P.& Speranzini,G. (2000). Collaborative problem solving through creativity in problem definition: Expanding the pie. *Creativity and Innovation Management*, *9*(1), 54-76. https://doi.org/10.1111/1467-8691.00157

Bienia, R. (2012). Why Do Players Larp? Motivations for Larping in Germany. In S. L. Bowman & A. Vanek (Eds.), *Wyrd Con companion 2012* (pp. 99–105). Wyrdcon.

Blanco, T. F., García-Piqueras, M., Diego-Mantecón, J. M., & Ortiz-Laso, Z. (2019). Modelización matemática de la evolución de dos reactivos químicos. *Epsilon*, (101), 147-155.

Bonney, R., Cooper, C. B., Dickinson, J., Kelling, S., Phillips, T., Rosenberg, K. V., & Shirk, J. (2009). Citizen science: a developing tool for expanding science knowledge and scientific literacy. *BioScience*, *59*(11), 977-984. https://doi.org/10.1525/bio.2009.59.11.9

Bowman, S. L. (2014). Educational live action role-playing games: A secondary literature review. In S. L. Bowman (Ed.), *The Wyrd Con Companion Book* (Vol. 3, pp. 112–131). Wyrd Con Los Angeles, CA.

Bowman, S. L., & Standiford, A. (2015). Educational Larp in the Middle School Classroom: A Mixed Method Case Study. *International Journal of Role-Playing*, *5*(1), 4–25.

Boytchev, P., & Boytcheva, S. (2019). Gamified Evaluation in STEAM. In R. Damaševičius & G. Vasiljevienė (Eds.), *Information and Software Technologies* (Vol. 1078, pp. 369–382). Springer International Publishing. https://doi.org/10.1007/978-3-030-30275-7_28

CEDEFOP. (2014). Rising STEMs. Recuperado el 17 de abril de 2018, de http://www.cedefop.europa.eu/en/publications-and-resources/statistics-and-indicators/statistics-and-graphs/rising-stems

Chai, C. S. (2019). Teacher professional development for science, technology, engineering and mathematics (STEM) education: A review from the perspectives of technological pedagogical content (TPACK). *The Asia-Pacific Education Researcher*, *28*(1), 5-13. https://doi.org/10.1007/s40299-018-0400-7

Clarke, S., Arnab, S., Keegan, H., Morini, L., & Wood, O. (2016). EscapED: Adapting Live-Action, Interactive Games to Support Higher Education Teaching and Learning Practices. In R. Bottino, J. Jeuring, & R. C. Veltkamp (Eds.), *Games and Learning Alliance* (Vol. 10056, pp. 144–153). Springer International Publishing. https://doi.org/10.1007/978-3-319-50182-6_13

Collier, C. (2016). How To Adopt A Collaborative Problem-Solving Approach Through 'Yes, And' Thinking Forbes Coaches Council Nov 21, 2016. https://www.forbes.com/sites/forbescoachescouncil/2016/11/21/how-to-adopt-a-collaborative-problem-solving-approach-through-yes-and-thinking/#4770ddd76694

Colucci-Gray, L., Burnard, P., Gray, D., & Cooke, C. (2019). A Critical Review of STEAM (Science, Technology, Engineering, Arts, and Mathematics). *Oxford research encyclopedia of education*. https://doi.org/10.1093/acrefore/9780190264093.013.398

Conde, M. Á., Rodríguez-Sedano, F. J., Fernández-Llamas, C., Gonçalves, J., Lima, J., & García-Peñalvo, F. J. (2020). Fostering STEAM through challenge-based learning, robotics, and physical devices: A systematic mapping literature review. *Computer Applications in Engineering Education*. https://doi.org/10.1002/cae.22354

Co-funded by the Erasmus+ Programme of the European Union

This project has been co-funded by the Erasmus+ programme of the European Union under grant no. 2020-1-ES01-KA201-082102.

de Freitas, S. I. (2006). Using Games and Simulations for Supporting Learning. *Learning, Media and Technology*, *31*(4), 343–358. https://doi.org/10.1080/17439880601021967

Deterding, S., Dixon, D., Khaled, R., & Nacke, L. (2011). From Game Design Elements to Gamefulness: Defining 'Gamification'. *Proceedings of the 15th International Academic MindTrek Conference on Envisioning Future Media Environments - MindTrek '11*, 9. https://doi.org/10.1145/2181037.2181040

Diego-Mantecon, J. M. (2020). Classroom implementation of STEM education through technology: advantages and handicaps. In P. R. Richard, S. Van Vaerenbergh & M. P. Vélez (Eds.), *First Symposium on Artificial Intelligence for Mathematics Education. Book of Abstracts* (AI4ME 2020) (pp. 9-10). Universidad de Cantabria.

Diego-Mantecón, J. M., Arcera, Ó., Blanco, T. F., & Lavicza, Z. (2019). An Engineering Technology Problem-Solving Approach for Modifying Student Mathematics-Related Beliefs: Building a Robot to Solve a Rubik's Cube. *International Journal for Technology in Mathematics Education, 26*(2), 55-64.

Diego-Mantecón, J. M., Blanco, T., Ortiz-Laso, Z., & Lavicza, Z. (2021). STEAM projects with KIKS format for developing key competences. [Proyectos STEAM con formato KIKS para el desarrollo de competencias clave]. *Comunicar*, *66*, 33-43. https://doi.org/10.3916/C66-2021-03

Diego-Mantecón, J. M., Ortiz-Laso, Z., & Blanco, T. F. (in press). Teaching mathematics through engineering technology projects: the important role of the teacher background.

Diez-Ojeda, M., Ortiz-Revilla, J., & Greca, I. M. (2019). Dificultades e impresiones sobre la implementación del proceso de diseño de ingeniería para la enseñanza de las ciencias en Educación Primaria. *Boletín ENCIC*, *3*(2), 44-46.

DOES 2014 English National Curriculum key stage 3 https://www.gov.uk/government/publications/national-curriculum-in-england-secondary-curriculum

Dörner, R., Göbel, S., Effelsberg, W., & Wiemeyer, J. (2016). Introduction. In R. Dörner, S. Göbel, W. Effelsberg, & J. Wiemeyer (Eds.), *Serious Games* (pp. 1–34). Springer International Publishing. https://doi.org/10.1007/978-3-319-40612-1_1

Dunn, S., & Hedges, M. (2018). From the wisdom of crowds to going viral: The creation and transmission of knowledge in the citizen humanities. In C. Herodotou, M. Sharples, & E. Scanlon (Eds.), Citizen inquiry: Synthesising science and inquiry learning (pp. 25-41). Routledge. https://doi.org/10.4324/9781315458618-3

Edelson, D. C., Gordin, D. N., & Pea, R. D. (1999). Addressing the challenges of inquiry-based learning through technology and curriculum design. *Journal of the Learning Sciences*, *8*(3–4), 391–450.

English, L. D. (2016). STEM education K-12: Perspectives on integration. *International Journal of STEM Education*, *3*(3). https://doi.org/10.1186/s40594-016-0036-1

English, L. D., King, D., & Smeed, J. (2017). Advancing integrated STEM learning through engineering design: Sixth-grade students' design and construction of earthquake resistant buildings. *The Journal of Educational Research*, *110*(3), 255-271. https://doi.org/10.1080/00220671.2016.1264053

European Commission. (2017). *White paper on the future of Europe*. Retrieved from https://ec.europa.eu/commission/sites/betapolitical/fles/white_paper_on_the_future_of_europe_en.pdf

European Commission. (2018). Council Recommendation of 22 May 2018 on key competences for lifelong learning (Text with EEA relevance.) https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32018H0604(01)

Faiella, F., & Ricciardi, M. (2015). Gamification and Learning: A Review of Issues and Research. *Journal of E-Learning and Knowledge Society*, *11*(3).

Fenyvesi, K., Houghton, T., Diego-Mantecón, J. M., Crilly, E., Oldknow, A., Lavicza, Z., & Blanco, T. F. (2017). Kids inspire kids for STEAM. *STEAM Journal*, *3*(1). https://doi.org/10.5642/steam.20170301.21

Filippou, J., Cheong, C., & Cheong, F. (2018). A Model to Investigate Preference for Use of Gamification in a Learning Activity. *Australasian Journal of Information Systems*, *22*(1), 1–24.

G.A.STEM. (2019). Enhancing STEM Skills through Arts and Mini-games. University of Turku.

Haas, B., Kreis, Y., & Lavicza, Z. (2020). Connecting the real world to mathematical models in elementary schools in Luxemburg. *Proceedings of the British Society for Research into Learning Mathematics*, *40*(2), 1–6.

Harviainen, J., Tuomas, D., Simkins, J., Stenros, E., MacCallum-Stewart, & Hitchens, D. (2018). Live-action role-playing games. In S. Deterding & J. Zagal (Eds.), *Role-Playing Game Studies: Transmedia Foundations*. Routledge.

Herodotou, C., Aristeidou, M., Sharples, M., & Scanlon, E. (2018). Designing citizen science tools for learning: lessons learnt from the iterative development of nQuire. *Research and Practice in Technology Enhanced Learning*, *13*(1), 1-23. https://doi.org/10.1186/s41039-018-0072-1

Herro, D., & Quigley, C. (2017). Exploring teachers' perceptions of STEAM teaching through professional development: implications for teacher educators. *Professional Development in Education*, *43*(3), 416-438. https://doi.org/10.1080/19415257.2016.1205507

Hennessy, S., & Murphy, P. (1999). The potential for collaborative problem solving in design and technology. *International Journal of Technology and Design Education*, *9*(1), 1-36. https://doi.org/10.1023/a:1008855526312

Houghton, T. (2019). Analysing Sporting Performance. https://prezi.com/m2mizmoz6x8m/analysing-sporting-performance-a-pisa-stem-toolkit/?present=1&webgl=0

Houghton, T. (2019 2). The Beauty of Movement. https://prezi.com/uutl69oyjro_/the-beauty-of-movement/?present=1&webgl=0

Houghton, A., Oldknow, A., Diego-Mantecón, J. M., Fenyvesi, K., Crilly, E., & Lavicza, Z. (2019). KIKS Creativity and Technology for All. *Open Education Studies*, *1*(1), 198-208. https://doi.org/10.1515/edu-2019-0014

Huotari, K., & Hamari, J. (2017). A Definition for Gamification: Anchoring Gamification in the Service Marketing Literature. *Electronic Markets*, *27*(1), 21–31. https://doi.org/10.1007/s12525-015-0212-z

Huotari, K., & Hamari, J. (2012). Defining Gamification: A Service Marketing Perspective. *Proceeding of the 16th International Academic MindTrek Conference on - MindTrek '12*, 17. https://doi.org/10.1145/2393132.2393137

IB Curriculum (2020). https://www.ibo.org/programmes/middle-years-programme/curriculum/

Irwin, A. (1995). *Citizen science: a study of people, expertise, and sustainable development*. Routledge.

Kapp, K. M. (2012). The Gamification of Learning and Instruction: Game-based Methods and Strategies for Training and Education. John Wiley & Sons.

Kang, N. (2015). The comparison between regular and flipped classrooms for EFL Korean adult learners. *Multimedia-Assisted Language Learning*, *18*(3), 41–72.

Kennedy, J., Lyons, T., & Quinn, F. (2014). The continuing decline of science and mathematics enrolments in Australian high schools. *Teaching Science*, *60*(2), 34-46.

Ketelhut, D. J., & Schifter, C. C. (2011). Teachers and Game-based Learning: Improving Understanding of How to Increase Efficacy of Adoption. *Computers & Education*, *56*(2), 539–546. https://doi.org/10.1016/j.compedu.2010.10.002

Kim, M. K., Lee, J. Y., Yang, H., Lee, J., Jang, J. N., & Kim, S. J. (2019). Analysis of elementary school teachers' perceptions of mathematics-focused STEAM education in Korea. *EURASIA Journal of Mathematics, Science and Technology Education*, *15*(9), em1746.

Co-funded by the Erasmus+ Programme of the European Union

This project has been co-funded by the Erasmus+ programme of the European Union under grant no. 2020-1-ES01-KA201-082102.

Kiryakova, G., Angelova, N., & Yordanova, L. (2014). Gamification in Education. *Proceedings of 9th International Balkan Education and Science Conference*. 9th International Balkan Education and Science Conference.

Kummanee, J., Nilsook, P., Piriyasurawong, P., & Wannapiroon, P. (2020). STEAM Gamification Learning Model to Enhance Vocational Students' Creativity and Innovation Skills. In M. E. Auer, H. Hortsch, & P. Sethakul (Eds.), *The Impact of the 4th Industrial Revolution on Engineering Education* (Vol. 1135, pp. 692–703). Springer International Publishing. https://doi.org/10.1007/978-3-030-40271-6_68

Lacanienta, A. (2020). Live Action Role-Play as Pedagogy for Experiential Learning. *SCHOLE: A Journal of Leisure Studies and Recreation Education*, 1–7. https://doi.org/10.1080/1937156X.2020.1718035

Lander, J. (2016). Students as Teachers: Exploring the mutual benefits of peer-to-peer teaching — and strategies to encourage it. https://www.gse.harvard.edu/uk/blog/students-teachers

Lavicza, Z., Haas, B., & Kreis, Y. (2020). Discovering Everyday Mathematical Situations Outside the Classroom with MathCityMap and GeoGebra 3D. *Research on Outdoor STEM Education in the DigiTal Age: Proceedings of the ROSETA Online Conference in June 2020*, 23–30.

Lavonen, J., Autio, O. & Meisalo, V. (2004) Creative and Collaborative Problem Solving in Technology Education: A Case Study in Primary School Teacher Education. *Journal of Technology Studies*, *30*(2), 107-115. https://doi.org/10.21061/jots.v30i2.a.8

Lieban D. (2019). PhD Exploring opportunities for connecting physical and digital resources for mathematics teaching and learning.

Malcolm, J., Hodkinson, P., & Colley, H. (2003). The interrelationships between informal and formal learning. *Journal of Workplace Learning*, *15*(7-8), 313-318. https://doi.org/10.1108/13665620310504783

Co-funded by the Erasmus+ Programme of the European Union

This project has been co-funded by the Erasmus+ programme of the European Union under grant no. 2020-1-ES01-KA201-082102.

Margot, K. C., & Kettler, T. (2019). Teachers' perception of STEM integration and education: a systematic literature review. *International Journal of STEM Education*, *6*(1). https://doi.org/10.1186/s40594-018-0151-2

Marrero, M. E., Gunning, A. M., & Germain-Williams, T. (2014). What is STEM education?. *Global Education Review*, *1*(4), 1-6.

Mayer, R. E. (2014). Computer Games for Learning: An Evidence-based Approach. The MIT Press.

Mayer, R. E. (2016). What Should Be the Role of Computer Games in Education? *Policy Insights from the Behavioral and Brain Sciences*, *3*(1), 20–26. https://doi.org/10.1177/2372732215621311

Mayer, R. E. (2019). Computer Games in Education. *Annual Review of Psychology*, *70*(1), 531–549. https://doi.org/10.1146/annurev-psych-010418-102744

McDonald, C. V. (2016). STEM Education: A review of the contribution of the disciplines of science, technology, engineering and mathematics. *Science Education International*, *27*(4), 530–569.

Michał, M. (2013). Edu-Larp as Revision of Subject-Matter Knowledge. *International Journal of Role-Playing*, *4*, 55–75.

Mildner, P., & 'Floyd' Mueller, F. (2016). Design of Serious Games. In R. Dörner, S. Göbel, W. Effelsberg, & J. Wiemeyer (Eds.), *Serious Games* (pp. 57–82). Springer International Publishing. https://doi.org/10.1007/978-3-319-40612-1_3

Nadelson, L. S., & Seifert, A. L. (2017). Integrated STEM defined: Contexts, challenges, and the future. *The Journal of Educational Research*, *110*(3), 221-223. http://dx.doi.org/10.1080/00220671.2017.1289775

National Research Council. (2012). A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas. The National Academy Press.

Opfer, V. D., Pedder, D. G., & Lavicza, Z. (2011). The role of teachers' orientation to learning in professional development and change: A national study of teachers in

England. *Teaching and Teacher Education*, *27*(2), 443–453. https://doi.org/10.1016/j.tate.2010.09.014

Ortiz, M., Chiluiza, K., & Valcke, M. (2016). *Gamification in Higher Education and STEM: A Systematic Review of Literature*. 6548–6558. https://doi.org/10.21125/edulearn.2016.0422

Pearson, G. (2017). National academies piece on integrated STEM. *The Journal of Educational Research*, *110*(3), 224-226. https://doi.org/10.1080/00220671.2017.1289781

Pedaste, M., Mäeots, M., Siiman, L. A., De Jong, T., Van Riesen, S. A., Kamp, E. T., ... & Tsourlidaki, E. (2015). Phases of inquiry-based learning: Definitions and the inquiry cycle. *Educational Research Review*, *14*, 47-61. https://doi.org/10.1016/j.edurev.2015.02.003

Rahmadi, I. F., Lavicza, Z., & Houghton, T. (2021). Towards User-generated Microgames for Supporting Learning: An Investigative Exploration. *Contemporary Educational Technology*, *13*(3), ep299. https://doi.org/10.30935/cedtech/10785

Rice, J. W. (2007). New Media Resistance: Barriers to Implementation of Computer Video Games in the Classroom. *Journal of Educational Multimedia and Hypermedia*, *16*(3), 249–261.

Richey, R. (Ed.). (2013). Encyclopedia of Terminology for Educational Communications and Technology. Springer.

Rieber, L., Barbour, M., Thomas, G., & Rauscher, D. (2009). Learning by Designing Homemade PowerPoint Games. In C. T. Miller (Ed.), *Games: Purpose and Potential in Education* (pp. 23–42). Springer US. https://doi.org/10.1007/978-0-387-09775-6_2

Robson, K., Plangger, K., Kietzmann, J. H., McCarthy, I., & Pitt, L. (2015). Is it All a Game? Understanding the Principles of Gamification. *Business Horizons*, *58*(4), 411–420. https://doi.org/10.1016/j.bushor.2015.03.006

Rojas-Drummond, S., Mazón, N., Fernández, M. & Wegerif R. (2006). Explicit reasoning, creativity and co-construction in primary school children's collaborative activities. *Thinking Skills and Creativity*, *1*(2), 84-94. https://doi.org/10.1016/j.tsc.2006.06.001

Sailer, M., & Homner, L. (2020). The Gamification of Learning: A Meta-analysis. *Educational Psychology Review*, *32*(1), 77–112. https://doi.org/10.1007/s10648-019-09498-w

Senabre, E., Ferran-Ferrer, N., & Perelló, J. (2018). Participatory design of citizen science experiments. [Diseño participativo de experimentos de ciencia ciudadana]. *Comunicar*, *54*, 29-38. https://doi.org/10.3916/C54-2018-03

Siko, J. P., & Barbour, M. K. (2012). Homemade PowerPoint Games: Game Design Pedagogy Aligned to the TPACK Framework. *Computers in the Schools*, *29*(4), 339–354. https://doi.org/10.1080/07380569.2012.734430

Shirk, J. L., Ballard, H. L., Wilderman, C. C., Phillips, T., Wiggins, A., Jordan, R., ... & Bonney, R. (2012). Public participation in scientific research: a framework for deliberate design. *Ecology and society*, *17*(2). https://doi.org/10.5751/es-04705-170229

Susi, T., Johannesson, M., & Backlund, P. (2007). *Serious Games: An Overview*. Institutionen för kommunikation och information, University of Skövde.

Thibaut, L., Ceuppens, S., De Loof, H., De Meester, J., Goovaerts, L., Struyf, A., ... & Depaepe, F. (2018). Integrated STEM education: A systematic review of instructional practices in secondary education. *European Journal of STEM Education*, *3*(1), 02. https://doi.org/10.20897/ejsteme/85525

Thibaut, L., Knipprath, H., Dehaene, W., & Depaepe, F. (2019). Teachers' attitudes toward teaching integrated STEM: The impact of personal background characteristics and school context. *International Journal of Science and Mathematics Education*, *17*(5), 987-1007. https://doi.org/10.1007/s10763-018-9898-7

Thomas, B., & Watters, J. J. (2015). Perspectives on Australian, Indian and Malaysian approaches to STEM education. *International Journal of Educational Development*, *45*, 42-53.

Thomas, M. (2013). Hothousing: New Concept or New Word? https://www.captechconsulting.com/blogs/hothousing-new-concept-or-new-word

Toma, R. B. (2020). Perceived Difficulty of School Science and Cost Appraisals: a Valuable Relationship for the STEM Pipeline?. *Research in Science Education*. https://doi.org/10.1007/s11165-020-09963-5

Toma, R. B., & Greca, I. M. (2018). The effect of integrative STEM instruction on elementary students' attitudes toward science. *Eurasia Journal of Mathematics, Science and Technology Education, 14*(4), 1383-1395. https://doi.org/10.29333/ejmste/83676

Toma, R. B., & Meneses-Villagrá, J. Á. (2019). Preferencia por contenidos científicos de física o de biología en Educación Primaria: un análisis clúster. *Revista Eureka sobre Enseñanza y Divulgación de las Ciencias, 16*(1), 1104. https://doi.org/10.25267/Rev_Eureka_ensen_divulg_cienc.2019.v16.i1.1104

Tseng, K. H., Chang, C. C., Lou, S. J., & Chen, W. P. (2013). Attitudes towards science, technology, engineering and mathematics (STEM) in a project-based learning (PjBL) environment. *International Journal of Technology and Design Education*, *23*(1), 87-102. https://doi.org/10.1007/s10798-011-9160-x

Vanek, A., & Peterson, A. (2016). Live Action Role-Playing (Larp): Insight Into an Underutilized Educational Tool. In K. Schrier (Ed.), *Learning, Education and Games* (Vol. 219). ETC Press.

Watson, W., & Yang, S. (2016). Games in Schools: Teachers' Perceptions of Barriers to Game-based Learning. *Journal of Interactive Learning Research*, *27*(2), 153–170.

Weinhandl, R., Lavicza, Z., & Houghton, T. (2020). Mathematics and STEM teacher development for flipped education. *Journal of Research in Innovative Teaching & Learning*, *13*(1), 3-25. https://doi.org/10.1108/jrit-01-2020-0006

Weinhandl, R., Lavicza, Z., Hohenwarter, M., & Schallert, S. (2020). Enhancing flipped mathematics education by utilising GeoGebra. *International Journal of Education in Mathematics, Science and Technology*, *8*(1), 1-15. https://doi.org/10.46328/ijemst.v8i1.832

Wiltschnig, S., Christensen, B. & Ball L. (2013) Collaborative problem–solution co-evolution in creative design. *Design Studies*, *34*(5), 515-542. https://doi.org/10.1016/j.destud.2013.01.002

This project has been co-funded by the Erasmus+ programme of the European Union under grant no. 2020-1-ES01-KA201-082102.

Annex 1: Publications

Diego-Mantecón, J. M., Ortiz-Laso, Z., & Blanco, T. F. (2022). Reflexiones del Open STEAM Group sobre el Impacto Integrado del Contenido en el Aprendizaje de las Matemáticas. In T. F. Blanco, C. Núñez-García, M. C. Cañadas, & J. A. González-Calero (Eds.), *Investigación en Educación Matemática XXV* (pp. 81-94). SEIEM.

Diego-Mantecón, J. M., Ortiz-Laso, Z., Diamantidis, D., & Kynigos, C. (2022). Toward a STEAM professional development program to exploit school mathematics. In J. Hodgen, E. Geraniou, G. Bolondi & F. Ferretti (Eds.), *Proceedings of the Twelfth Congress of the European Society for Research in Mathematics Education* (pp. 4579-4580). Free University of Bozen-Bolzano and ERME.

Diego-Mantecón, J. M., Prodromou, T., Lavicza, Z., Blanco, T. F., & Ortiz-Laso, Z. (2021). An attempt to evaluate STEAM Project-Based Instruction from a school mathematics perspective. *ZDM – Mathematics Education.* https://doi.org/10.1007/s11858-021-01303-9

Houghton, T., Lavicza, Z., Rahmadi, I. F., Diego-Mantecón, J. M., Fenyvesi, K., Weinhandl, R., & Ortiz-Laso, Z. (2022). STEAMTEACH Austria: Towards a STEAM Professional Development Program. *International Journal of Research in Education and Science*, *8*(3), 502-512. https://doi.org/10.46328/ijres.2747

Co-funded by the Erasmus+ Programme of the European Union

This project has been co-funded by the Erasmus+ programme of the European Union under grant no. 2020-1-ES01-KA201-082102.

Annex 2: Semi-structured interview guide

Semi-Structured Interviews Guide for Trainers
Date: Time (minutes):
Background characteristics of the trainers
• Name: • Nationality: • Age: • Academic title: • What is your position in the teacher-training organization? • Years of experience as STEAM trainer: • What methodology are you applying for delivering STEAM education to Secondary school teachers? e.g., Project Based Learning, Inquiry Based Learning, Gamification, Problem Solving Learning, and so on. • What subjects are you normally integrating in your courses? E.g., Science (biology, physics, or chemistry) and technology? Engineering and Maths? Maths and Arts (Art, Social Sciences, or Humanities)? Others?
Obstacles to teach the STEAM Approach and Recommendations to overcome them
1. What methodology or approach would you recommend for delivering STEAM education? Why? 2. Generally speaking, what are the greatest challenges to effectively teach and implement integrated approaches to STEAM education? 3. Please, specifically indicate the best methodologies/approaches to deliver STEAM education and explain their main handicaps or challenges. 4. What recommendations would you give to overcome the aforementioned challenges for each methodology?

5. What recommendations for pre-service education could help teachers better integrate STEAM subjects?
6. What recommendations for in-service or continuing professional development would help support integrated STEM education?

Semi-Structured Interviews Guide for trainers who are also school teachers

Date:

Time (minutes):

Background characteristics of School Teachers

- Name:
- Nationality:
- Age:
- What is your position in the school? (e.g., director, teacher, etc.)
- Academic title:
- Years of experience implementing STEAM activities/projects:
- What methodology are you applying for delivering STEAM education in your classroom? e.g., Project Based Learning, Inquiry Based Learning, Gamification, Problem Solving Learning, and so on.
- What subjects are you normally integrating in your lessons? e.g., Science (biology, physics, or chemistry) and technology? Engineering and Maths? Maths and Arts (Art, Social Sciences, or Humanities)? Others?

Obstacles to implement the STEAM Approach and Recommendations to overcome them

1. What methodology or approach would you recommend for delivering STEAM education? Why?
2. Generally speaking, what are the greatest challenges to effectively implementing integrated approaches to STEAM education?
3. Please, specifically indicate the methodology/ies or approach/es you use for implementing STEAM education in your classroom? Why do you use it? Explain their main handicaps or challenges.
4. What recommendations would you give to overcome the aforementioned challenges?

This project has been co-funded by the Erasmus+ programme of the European Union under grant no. 2020-1-ES01-KA201-082102.

5. What recommendations for pre-service education could help teachers better integrate STEAM subjects?
6. What recommendations for in-service or continuing professional development would help support integrated STEM education?
7. Are you collaborating with other teachers in your school for implementing STEAM activities? What type of collaboration is it?
8. Are you receiving support from your school to effectively implement STEAM in your classroom?
9. Are you noticing a good response from the students' families to the STEAM approach? Are parents collaborating in their daughters/sons learning process in the same way they do with other subjects?
10. Why did you begin to apply the STEAM education in your classroom? Have you ever received STEAM training courses? How many and what type of course?

This project has been co-funded by the Erasmus+ programme of the European Union under grant no. 2020-1-ES01-KA201-082102.