WP2

STEAM context, concepts and conditions

Deliverable 2.3 Analysis of conditions and requirements

Deliverable 2.3

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Revision History

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Abstract

This report constitutes deliverable Deliverable 2.3 “Analysis of conditions and requirements” of the Road-STEAMer project. It concludes Task 2.3 in the second work package (WP2) of the Road-STEAMer project. WP2 began with an examination of the socioeconomic landscape and needs for STEAM education in Europe (task 2.1), followed by the development of a conceptual framework for STEAM education (task 2.2). The current report marks the final step in WP2, analyzing the conditions and requirements for effective integration of STEAM in education. It builds upon earlier WP2 deliverables, D2.1 and D2.2, as well as D4.1 from WP4 which outlines criteria for mapping and analyzing STEAM practices.

Overall, the present report offers a thorough examination of the practical considerations and necessities for effectively implementing STEAM practices in education. It views STEAM as an innovative approach to integrate into everyday educational settings in Europe’s schools, addressing the associated conditions, challenges, and opportunities. Key aspects explored in our study include curriculum development, teacher training and professional development, and school management and leadership, all crucial components of educational innovation that must be carefully evaluated to outline essential conditions and requirements for integrating and mainstreaming STEAM practices in education.

Our analysis draws from literature reviews, workshops, and questionnaire surveys, combining the findings from the project background (deliverables D2.1, D2.2, D4.1) with insights from academic and practitioner knowledge regarding educational change and innovation introduction. Additionally, we consider the potential synergies between STEAM and current trends and policy issues in European education.

Moving forward, this report will guide the next steps of Road-STEAMer toward developing the STEAM roadmap for science education in Horizon Europe. One of the questionnaire surveys we deployed, the “Final questionnaire”, remains open to gather further responses, aiming to enhance the project's understanding of the conditions and requirements for STEAM education across a broader range of respondents and European contexts. This additional input could significantly contribute to future project deliverables, including D3.2 "Analysis of policy gaps for STEAM," D4.3 "Report on real-life use-cases," as well as D5.1 and D5.2 "STEAM roadmap for science education in Horizon Europe."

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1. Introduction

1.1 About Road-STEAMer

The overall aim of the Road-STEAMer project is to develop a STEAM roadmap for science education in Horizon Europe, i.e. a plan of action that will provide guidance to EU's key funding programme for research and innovation on how to encourage more interest in STEM through the use of artistic approaches, involving creative thinking and applied arts (the "A" in 'STEAM').

The consortium aims to provide Europe with this roadmap, through:

Collaboration and co-creation with the stakeholder communities of science education, research, innovation and creativity, through intensive exchange, dialogue and mutual learning among them which will produce better knowledge and shared understandings of the relevant opportunities, challenges and needs.

A bottom-up approach emphasizing educational practice and practitioners' agency rather than high-level conceptualizations of STEAM and generic top-down plans (in reality often just vague statements of intention) for its adoption in science education.

A specific focus on ways to leverage the power of STEAM approaches, as manifested through exemplary cases and best practices, so as to enable a bridging of open science and open schooling which can catalyse an increased impact for science education as a crucial tool for addressing Europe's current scientific and societal challenges.

1.2 About this deliverable

This report is based on the work carried out in Task 2.3, within the second work package (WP2) of the Road-STEAMer project. It constitutes the third and final step in WP2, which aims to provide a rigid framework for the whole of Road-STEAMer, through a comprehensive analysis of STEAM concepts, contexts, and conditions.

This includes an initial analysis of the wider socioeconomic context and needs for STEAM education in Europe (task 2.1), which subsequently forms the background for the development of a comprehensive conceptual framework for STEAM education (task 2.2), covering its various aspects and potential. Finally, based on these

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contextual and conceptual foundations, WP2 aims to analyse the conditions and requirements for effective introduction of STEAM in education.

The results of the work in the first step were reported in deliverable D2.1 “Socio-economic context and relevant needs”, in the early phase of Road-STEAMer (forst version submitted in M6, and revised/expanded version submitted in M18). The second step produced deliverable D2.2 “Conceptual framework for STEAM”, at the end of the first project year (M12). The present report constitutes the third and final deliverable of WP2, D2.3 “Analysis of conditions and requirements”, which is being delivered halfway through the three-year project (M18). It is building on the previous deliverables of WP2, D2.1 and D2.2, as well as on deliverable D4.1 “Research framework” from WP4, in which the criteria for mapping and analysing STEAM practices are provided.

1.2.1 Summary of the background

Analysis of the socioeconomic context and needs for STEAM education in Europe

The first element of the background to the present deliverable is the initial analysis of the wider socioeconomic context and needs for STEAM education in Europe, which was reported in deliverable D2.1. Based on extensive desk research including literature reviews and secondary data analyses, which were followed by a co-creation workshop with consortium members, that part of WP2 work produced a number of important findings.

It indicated that STEAM participation and achievements are heavily impacted by the family’s socio-economic condition as well as their educational and science capital, while intersectional aspects such as gender and migration background add to the under-representation of diverse groups. Thus, there is a need for widened sociocultural participation and deconstruction of STEAM stereotypes. In addition, instead of looking at the phenomenon from the “leaky pipeline” perspective, where certain groups of people drop out, it was noted that there should be a shift towards a “hostile obstacle course” placing the focus away from individuals onto systematic barriers at different levels.

Further, it was concluded that in times of the COVID-19 epidemic and other complex challenges the world is facing, like climate change and loss of biodiversity, there is not only the need for more scientists but also for a more positive attitude and advanced

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understanding of science by society. It was noted that different mechanisms can improve the attitude toward science and interest in science, such as diverse role models changing the image of science, increased science communication, and stakeholder involvement at schools linked to dealing with real-life, tangible problems.

From the industry side, too, it was noted that the demand for STEAM graduates is high and is expected to increase in the future with digital skills playing a crucial role. However, it is not only “technical skills” that are needed but also their combination with “soft skills” such as intercultural understanding.

Overall, the STEAM approach was found to be promising and necessary for addressing current challenges, such as the need of increasing digital and scientific literacy, the issue of inclusivity of women and minorities in scientific fields, and the need to develop skills to face grand challenges such as global warming, health and inequalities. Yet, it was pointed out that the available scientific knowledge is not comprehensive enough to account for the multiplicity of factors that impact STEAM effectiveness in addressing the above mentioned issues, in particular for (1) disentangling the impact of the arts (integrated into STEM subjects or provided as separate subjects) from the impact of open and collaborative teaching practices, and (2) assessing the impact of contextual and moderating factors such as socio-economic background, ethnicity, age, cultural context, media influence, and personal differences. In other words, the results highlighted that more scientific studies are needed to test precisely which approach works better for whom and when.

Deliverable D2.1 concluded with recommendations on overcoming some of the identified challenges and fulfilling the needs for STEAM. Table 1 provides a structured summary of those recommendations, classified according to categories of key emerging societal needs and related benefits of the STEAM approach.

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Table 1: Recommendations based on the analysis of the socio-economic context and needs for STEAM education (from D2.1)

Societal needs	**Barriers of STEM**	**Benefits of STEAM**	**Recommendations**
1. More scientists	-Science is perceived as difficult -Not all schools offer STEAM subjects	-More emotional, appealing and fun by including arts -Value 'Art' as a way of enhancing self-confidence and facilitate the development of personal opinions and critical thinking -STEAM as a way to break down STEM stereotypes	-More research on STEAM education effectiveness (Arts in addition and/or integrated with STEM) -Make science learning inclusive and appealing: teachers have STEAM easy-to-use material -Communicate to schools and teachers the values of the STEAM approach -Expose students to science careers from the early years -Expose students to science role models from primary years -Value STEAM approach: supporting young people to bring these subjects together, a holistic and subject integrative view is necessary.
2.Alignment of industry and societal needs with education	Provides only technical skills but organisations need workers with soft skills and intercultural abilities	-Arts integrated in STEM courses promote intercultural and collaborative skills -Real world problems are multidisciplinary by default	-Open schools (and other real world approaches) -Data on industries and organisations' needs are used to support education policies -Project-based collaborative learning to develop soft skills and inclusivity -Multidisciplinary and interdisciplinary projects -Support entrepreneurship and self-employment
3.More diversity (gender, ethnic, socioeconomic, etc.)	Science career is perceived as not in line with identity of women and minorities	-Arts subjects are more appealing and relatable for diverse people -Diversity improves organizational outcomes	-Policy to affect structural changes (inclusion, access, diversity,…) -Address gaps in abstract thinking/maths from the primary school years -Replace the leaky pipeline metaphor with epistemic justice -Role models to redefine identities and change culture -Include families to change science stereotypes -STEAM focused career training -More research on moderating factors and career paths to optimise policies (e.g. family's attitude, education and career choices, engagement, parents' STEM experience) -Analyse the impact of national differences in school systems

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Societal needs	Barriers of STEM	Benefits of STEAM	Recommendations
4. Increase science literacy for all	Science is perceived as difficult or there is lack of awareness	-STEAM as a way to break down STEM stereotypes -Match hard topics with arts to lower perceived barriers and increase interest	-Better connection between the needs of the labour market and lifelong learning -Provide sufficient professional development and training of educational professionals - Develop digital literacies (note 'literacies' instead of 'literacy') beyond computer science - Focus on societal challenges and real problems to promote interest in science -Integrate the need for scientific thinking also in non-scientific/arts topics - Acknowledge the imbalance of financial support for 'Arts' and how these issues could be re-addressed in STEAM - Promote positive attitudes towards STEAM

Deliverable D2.1 was concluded with the apt note that, although the recommendations above are listed according to categories with the purpose of providing a cognitively efficient summary, the reality is complex and multi-faceted, with recommendations being related to more than one challenge and often interacting. It is therefore necessary, it was noted, that in the next steps of developing the Road-STEAMer Roadmap the project should consider the interactions (both positive and negative) between the recommendations and the identified societal needs in a systemic manner.

STEAM conceptual framework and criteria for analysing STEAM practices

The second element of the background to the present deliverable is the comprehensive conceptual framework for STEAM that was presented in deliverable D2.2. Building further on D2.1, through a systematic literature review of resources theorizing or conceptualizing STEAM as well as a co-creation workshop with academics and practitioners, this valuable work synthesised theoretical approaches linked to STEAM practice in the literature in relation to the Road-STEAMer foci: a) using artistic approaches involving creative thinking and applied arts (the "A" in STEAM); b) connecting to open schooling and open science; and c) at the secondary-tertiary interconnection. The thematic analysis of the literature resources resulted in a synthesis of the breadth of theoretical approaches linked to STEAM practice in the literature, with the heart of the Road-STEAMer conceptual framework emerging as

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grounded in relationality. Further, the analysis produced a set of four groups of approaches:

- Experiential, real-world interaction approaches
- Human psychological and cognitive approaches
- Social, spatial and material interconnectivity approaches
- Cultural and equity approaches.

These groupings were analysed and explored to identify how each connects to the criteria for mapping and analysing STEAM practice which were defined in deliverable D4.1 “Research Framework”. That work was conducted in parallel to the development of the conceptual framework with the aim to define an initial outline of criteria that the Road-STEAMer project will use to map and analyse STEAM practices in Europe. For this, the team identified, thematically analysed and categorised published literature and projects. Following an initial in-depth analysis, a co-creation workshop was held to refine and clarify the criteria to be used.

Equity was identified as an underlying principle and value that supports all STEAM practice and is therefore an all-pervading criterion.

The key criteria were identified as:

- Collaboration
- Disciplinary inter-relationships
- Thinking-making-doing
- Creativity
- Real-world connection, and
- Inclusion/Personalisation/Empowerment.

Deliverable D4.1 explains in detail how these criteria are reached, the published work on which they are based, and offers a description of each.

The coupling of the above criteria (D4.1) with the four approaches identified in the conceptual framework (D2.2), both grounded in extensive literature reviews and co-

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creation workshops, form a solid basis for the conceptualization of STEAM education by Road-STEAMer. As argued in D2.2, this broad conceptual framework enables well-grounded conceptual understanding of STEAM practices and is of use to policymakers and practitioners in creating the conditions for, and designing, STEAM practice that is effective in achieving key goals identified in deliverable D2.1. Therefore, this background forms the foundation for the work reported in the present deliverable.

1.2.2 This work and its methodology

Building on the above basis, the work reported in the present deliverable aims to provide a comprehensive analysis of the real-life conditions and requirements for the effective integration of STEAM practices in education. Thus, the focus here shifts from the wider socioeconomic environment and the conceptualization and analysis of STEAM practices to STEAM as an innovation to be introduced into everyday educational practice in Europe's schools, and the conditions, requirements, challenges and opportunities linked to this change in the practical realities of education.

In this sense, central considerations of the work reported here are aspects of educational practice such as the curriculum, teachers and their training and professional development, school organization and leadership and characteristics of educational systems. These are important facets of educational innovation and change that need to be carefully considered in order to highlight important conditions and requirements for any attempt to integrate and mainstream STEAM approaches in education.

To this end, we mapped the results of the background work (D2.1, D2.2, D4.1) summarised in the previous sections, with academic and practitioner knowledge about educational change and the introduction of innovations in education. Given the extensive literature reviews that had been carried out in the earlier stages of the project, we did not need to focus our study on any further review of literature resources specific to STEAM practices. Instead, we studied in detail the interplay of the results of Road-STEAMer's socioeconomic and conceptual analysis of STEAM approaches and practices with the key messages on educational change and the introduction of innovation in education which emerged from the literature, as well as from our interaction with the stakeholder community described further below. The results of this analysis are presented in sections 2.1 and 2.2 of this report.

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In our analysis we also included an appreciation of the opportunities arising for the integration of STEAM in education from possible links and synergies with current tendencies and topical issues in education and policymaking at the European level. These include aspects such as open schooling approaches to education, efforts towards creating an integrated learning continuum through synergies between formal, informal and non-formal education, practices such as making and digital fabrication linked to design thinking, playful learning, as well as links to the big challenges of our times and their reflection in relevant European policy areas such as the Green Deal, Digitisation, and Health. We report on these aspects of our analysis in section 2.3 of this report.

In order to produce shared understandings and further evidence from the community, and implementing the overall participatory methodology of Road-STEAMer (cf. deliverable D1.1), we informed our emerging understanding of the conditions and requirements for the integration of STEAM in education, with input from four workshops: three workshops with educators, and a workshop with the participation of consortium partners.

The discussions during the workshops aimed to delve deep into the conditions and requirements for the introduction of STEAM in education. We based these discussions on a list of key notions, which we produced through an initial analysis of the conceptual background that deliverables D2.1, D2.2, and D4.1 provided. These key notions, organised under the STEAM practice criteria of D4.1, are listed in Annex 1.

The collection of workshop participant views and suggestions was facilitated through the use of a series of questions which we organized into two online questionnaires that participants completed during or after the workshops: The "Questionnaire exploring conditions and requirements for the effective integration of STEAM in education" ("Exploratory questionnaire") and the "Questionnaire on barriers to the effective integration of STEAM in education" ("Barriers questionnaire"). Both instruments included carefully devised multiple-choice, Likert-scale and open-ended questions which comprehensively covered the aspects of STEAM integration in education under investigation. The Exploratory questionnaire gathered responses from 52 workshop participants, while the Barriers questionnaire was completed by 37 workshop participants. These two questionnaires are presented in Annexes 2 and 3 respectively.

Based on the results of the discussions during the workshops and the analysis of the data collected through the Exploratory and Barriers questionnaires, we subsequently

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produced the “Final questionnaire on the conditions and requirements for the effective integration of STEAM in education” (“Final questionnaire”), aiming to generate consolidated evidence from a wide range of European contexts on the conditions and requirements for STEAM education. We have administered this survey widely, promoting it in Europe through our partners in the Road-STEAMer consortium and our extensive networks of collaborating school communities in several countries. The survey remains open and continues to collect responses, as part of our ongoing work, which we have decided to expand beyond the formal completion of Task 2.3 in order to keep informing the next steps in the project with more data. By the time of preparing the final draft of the present report, the Final questionnaire has gathered responses from 110 participants coming from 20 countries. The Final questionnaire is presented in Annex 4.

The geographical focus of the above interaction with the stakeholder community varied, aiming to combine both a wide coverage of Europe with an in-depth investigation of the conditions and requirements for the integration of STEAM in education, which often tend to be context sensitive. Thus, the participants of the educator workshops where teachers from Greece, where the core of the Task 2.3 team is based. The consortium workshop was attended by individuals from the 10 countries participating in Road-STEAMer (Austria, Belgium, France, Greece, Italy, Malta, Netherlands, Poland, Ukraine, United Kingdom), which represent a wide range of geographical, socioeconomic and cultural aspects of Europe. Further, the Final questionnaire respondents, by the time of preparing the final draft of the present report, come from 18 European countries (Austria, Belgium, Cyprus, Germany, Greece, Israel, Italy, Lithuania, Malta, Moldova, Netherlands, Norway, Poland, Portugal, Romania, Spain, Ukraine, United Kingdom) as well as USA and Canada.

Our decision to enrich our desk research, at the earlier stages of our study, with educators’ voices from one country context was based on the understanding that educational innovations are deeply embedded within the social, cultural, material, and political contexts which shape their use and impact. For this reason, implementing educational innovations successfully necessitates a context-specific analysis of the relevant conditions and requirements. Thus, we used our close interaction and exchanges with educators from Greece as a means to highlight details that are context-specific. At the same time, by reviewing relevant international literature, by discussing within the international Road-STEAMer consortium, and by collecting stakeholders’ views from a wide range of countries through the Final questionnaire, we provide an

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analysis of the conditions and requirements for the introduction of STEAM at a higher, more generic, Europe-wide level.

On this background, the present report was produced through a meticulous analysis and synthesis of the information and data generated through the study of the background project documents (D2.1, D2.2, D4.1), the literature review, the workshop discussions, and the responses to the three questionnaires. Initially, a thorough thematic reading of literature on educational change and the introduction of innovation in education was conducted to establish a comprehensive understanding of existing theories, concepts, and empirical findings pertinent to the question about the conditions and requirements for the integration of STEAM in education. The thematic reading was structured around the key notions that emerged from the background project reports (summarised in Annex 1), combined with the central aspects of educational practice we have focused upon, namely the curriculum, teachers, teacher training and professional development, school organization and leadership. This literature review served as the foundation for our study, allowing us to identify key themes, gaps, and areas of interest relating to the conditions and requirements for the integration of STEAM in education. Concurrently, detailed notes gathered from the workshops we conducted, as well as the data gathered through the questionnaires, were integrated into the analysis process. These notes and data provided invaluable insights into real-world experiences and perspectives shared by the participants. By synthesizing the insights gleaned from both the thematic reading of literature and the rich data obtained from the workshops and questionnaires, we were able to develop a nuanced understanding of the conditions and requirements for the integration of STEAM in today's education. This integrated approach enhanced the depth and richness of our analysis, and facilitated the formulation of meaningful interpretations and conclusions presented in this report.

The present report is delivered in a timely fashion to inform the next steps of the Road-STEAMer project towards the STEAM roadmap for science education in Horizon Europe, formally marking the completion of WP2. Nevertheless, we see our research on the conditions and requirements for the integration of STEAM in the practical realities of education as ongoing work that will continue throughout the project, being in constant discourse with the analyses of policies (WP3) and practices (WP4) and an important constituent for the final synthesis of the STEAM roadmap (WP5). On the basis of the understandings gained through the study presented in this deliverable and as part of our ongoing work, we are keeping the Final questionnaire survey open,

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aiming to generate further and stronger evidence on the conditions and requirements for STEAM education, from an even wider range of respondents and European contexts, and use this to inform subsequent outputs of the project. Such auxiliary input could be useful, for instance, in deliverables D3.2 “Analysis of policy gaps for STEAM”, D4.3 “Report on real-life use-cases”, as well as D5.1 and D5.2 “STEAM roadmap for science education in Horizon Europe”.

The remainder of this report, following the present introductory section, is organized into three parts. In Section 2 we present the main discussion of all aspects of the introduction of STEAM in education as a case of educational innovation and change. In Section 3 we present a relevant analysis of specific examples of STEM practices, addressing questions relating to the connection with the curriculum in order to highlight some of the more specific conditions and requirements for the integration of STEAM in education. And, finally, in Section 4 we summarise the conclusions of this study and present further steps to be taken based on these.

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2. STEAM as educational innovation and change

2.1 Understanding the introduction of STEAM comprehensively

To understand the contextual factors that influence the introduction and uptake of an innovation such as STEAM in education, it is required to see the educational landscape as constantly evolving, driven by a dynamic interplay of advances in pedagogy, socio-cultural shifts and technological disruptions (Fullan, 2015). As part of this dynamic, educational innovations emerge promising to revolutionize learning experiences and outcomes, in response to perceived needs and demands (Cuban, 1988). However, the journey from promising idea to widespread adoption is rarely smooth, and contextual factors play a critical role in determining the success or failure of any educational innovation. As is true for the adoption of new ideas more generally (Rogers, 2003), in education too influential factors include the perceived value of the innovation, its complexity, and its compatibility with existing practices. In our effort to understand the conditions and requirements for the wide introduction of STEAM education into school practice, we therefore need to take into account the complex interplay of these contextual factors which influence the uptake of educational innovations.

Rogers (2003) serves as a foundation for understanding the adoption of innovations across various fields, including education, proposing a comprehensive framework which examines factors like relative advantage, compatibility, and complexity that influence individual decisions to adopt new practices. Further, Fullan (2020) delves deeper into the school-level factors that impact successful implementation, emphasizing the importance of leadership, collaboration, and building capacity within the school community to navigate change effectively. Drawing on frameworks such as the Diffusion of Innovation Theory (Rogers, 2003) and Implementation Science (Fullan, 2015), several key areas of influence can be identified.

At the individual level, factors like teachers' perceptions of the innovation's relative advantage, compatibility with existing practices, and complexity significantly impact their willingness to adopt (Means et al., 2001). Additionally, teacher characteristics such as age, experience, and professional development opportunities shape their

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readiness for change (Holmes et al., 2013). Beyond individual factors, the school and community context play a crucial role. School leadership committed to innovation, coupled with a collaborative culture among educators, fosters an environment conducive to implementation (Fullan, 2020). Guskey (2000) emphasizes the importance of effective professional development, ongoing assessment, and building a culture of shared responsibility. Furthermore, systemic factors like funding, infrastructure, and policy frameworks can act as enablers or barriers (Penuel et al., 2007). The broader socio-cultural context also plays a significant role. Cultural beliefs and expectations regarding education can influence the acceptance of new approaches, and socioeconomic disparities and equity considerations must be addressed to ensure inclusive implementation (Means et al., 2001). Moolenaar et al. (2021) adds further valuable insights, highlighting the crucial role of external context, including policy frameworks, social norms, and available resources, in shaping the uptake of new programs and interventions.

Considering these individual, school, community, and broader socio-cultural contextual factors is crucial for designing effective strategies to promote the successful uptake of any educational innovation coherently and comprehensively (Fullan and Quinn, 2016), including the introduction of STEAM practices in Europe's schools. More generally, understanding the dynamic interplay of various contextual forces in STEAM implementation aligns with the broad need to carefully consider contextual factors in science education research to avoid the risk of limiting generalizability and applicability (Martin, 2010).

Taking a step further, to transcend simplistic explanations and embrace the complexity of factors influencing the introduction of innovative STEAM practices into education, we can utilize multi-layered, systemic lenses offered by frameworks such as Cultural-Historical Activity Theory (CHAT) (Engeström, 2007), which proves valuable in examining how individuals, tools, and social contexts interact to shape STEAM learning. What is more, beyond individual teacher adoption, teacher agency (Fullan and Hargreaves, 2015) needs to be considered, including how school structures and leadership practices influence and support their engagement with these novel approaches (Leithwood and Fullan, 2012).

2.1.1 Contextual factors

On this background, we can broadly categorise the various contextual factors that can influence the uptake of STEAM education into three main levels:

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Individual level:

- **Teacher characteristics**, including their age, experience, technological fluency, beliefs about teaching and learning, as well as the perceived need for introducing STEAM and their intrinsic motivation for that, can all influence a teacher's willingness to adopt STEAM practices.

- **Student characteristics**, including prior knowledge, learning styles, and socioeconomic background can impact how students respond to and benefit from STEAM practices.

School level:

- **Leadership**, as school leaders who are supportive of innovation and provide resources and professional development can create a more receptive environment for change and the introduction of STEAM practices.

- **School culture**, as schools with a collaborative and open culture where experimentation is encouraged are more likely to see successful implementation of innovations such as STEAM.

- **Resources**, including the availability of technology, infrastructure, and funding, all of which can play a significant role in facilitating the adoption of STEAM practices.

Wider environment level:

- **Curriculum frameworks**, as educational policies and curriculum mandates can influence the types of innovations that are promoted, supported or accepted in a given educational context, including STEAM practices.

- **Social norms and expectations**, since community expectations, parental involvement, and public perception of the innovation can all affect the uptake of STEAM.

- **Professional development and support**, including access to ongoing teacher training and support provision which can help educators successfully implement innovative STEAM practices.

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2.1.2 STEAM inherent factors

In addition to the above contextual factors, various innovation characteristics can influence the uptake of an educational innovation such as the introduction of STEAM practices. Following Rogers (2003), such inherent factors include the following:

- **Relative advantage**, i.e. the perceived benefit of innovative STEAM practices over existing practices.
- **Trialability**, i.e. possibility to experiment and test STEAM practice first on a small scale before implementing it more broadly.
- **Observability**, i.e. visibility of the benefits and successes of STEAM.
- **Compatibility**, i.e. how well STEAM innovation aligns with existing values and practices.
- **Complexity**, relating to the ease of 'learning' and implementing STEAM.

Further to these general innovation characteristics, certain specific traits of STEAM practice naturally impact on the conditions and requirements for the effective introduction of STEAM in education.

Generally, we can describe STEAM as a paradigm shift in educational approaches. It moves beyond the traditional silos of individual disciplines to create an integrated learning environment where Science, Technology, Engineering, Arts, and Mathematics intersect and complement each other (Quigley et al., 2017). This approach aims to encourage students to apply knowledge and skills from various fields to solve real-world problems, preparing them to be active and responsible members of society (Sochacka et al., 2016). By breaking down disciplinary barriers, STEAM fosters collaborative work among students with diverse interests and skill sets, promoting teamwork, communication, and negotiation skills (Connor et al., 2015). STEAM practices emphasize hands-on, project-based learning activities that engage students in active exploration and discovery, encouraging them to ask questions, conduct investigations, and collaborate to find solutions (Sochacka et al., 2016). This approach not only enhances students' understanding of how STEM disciplines impact their lives but also cultivates creativity and innovation by integrating artistic expression into the learning process (Peppler & Wohlwend, 2017). By incorporating arts into STEAM education, students are provided with tools for problem-framing, visualization, and

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communication, fostering essential skills for navigating the complexities of the 21st century (Peppler & Wohlwend, 2017). Furthermore, STEAM education offers a transdisciplinary learning process that has the potential to increase diverse participation in STEM fields (Quigley et al., 2017). It promotes a shift from traditional lecture-based teaching to a more creative and open-ended learning approach, typical in art education (Tovar et al., 2018). Through STEAM, students and educators have the opportunity to explore connections between materials, design, society, and the natural environment, critically engaging with various facets of disciplinary identity (Sochacka et al., 2016).

In the context of the Road-STEAMer project in particular, work conducted so far particularly highlights aspects and characteristics of effective STEAM education such as those described in the following paragraph, which constitutes a digest of the concepts and arguments presented in deliverables D4.1 and D2.2 produced for the purposes of the present study.

Envisaged effective STEAM practice can be seen as a vibrant tapestry of learning, creativity, and empowerment for all, which transcends mere disciplinary integration. The real world provides the context for STEAM practice, foregrounding exploration of cutting-edge issues and addressing 'wicked problems' of our times, connecting the educational practice to broader societal concerns as well as to civic engagement and entrepreneurship. Problem-solving and authentic tasks are shaped around student choice and problem ownership, as well as focusing on being co-creative: they are not just about finding solutions, but also about collaborative hands-on design, production, and exploration. Students actively engage in learning which embraces uncertainty and encourages experimentation and flexibility. This kind of learning is not just about rote knowledge but rather about making, doing, and questioning, thus fostering diverse cognitive skills including system thinking, critical thinking, creative thinking, divergent/convergent thinking and in this way contributing to 21st-century competencies. Arts become catalysts for creativity, innovation, and connection between disciplines. Creativity is the vibrant thread that runs through it all, with creative STEAM pedagogies promoting identity development, empowerment, fostering individual expression and personal meaning-making. They are also linked to joyful engagement, as well as to design thinking empowering students to create and connect across disciplines towards open-ended innovation. Teachers are expected to facilitate, guide, advise, and counsel, fostering student-led learning and creativity. They are also eager to share expertise and resources among them, breaking down disciplinary silos

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and promoting collective growth. Students do not just work with peers and teachers, but also connect with external partners including local communities and stakeholders, which fosters not only collaboration and teamwork but also negotiation and diverse perspectives. Technology, from collaborative design tools to gamified learning experiences, may empower exploration and co-creation. Last but not least, inclusivity and equity are cornerstones of this shared creative and learning space, manifesting themselves in several ways. For one thing, covering a wider range of interests, arts integration attracts diverse learners and makes STEAM more inclusive than STEM alone. In addition, STEAM empowers young people, and especially under-represented groups, to embrace their identities as change-makers and develop their science capital and identity. An affirmative ethical stance is also integral, by valuing all disciplines, promoting equity and challenging traditional hierarchies.

2.2 Key areas of conditions and requirements for STEAM

2.2.1 Curriculum: making STEAM an integral part

The relation between STEAM practices and the curriculum is one of the predominant factors impacting the introduction of STEAM in education. To shed light on this relation, it is necessary to consider the key constituents of the curriculum and the forces that shape it, as those are identified and widely understood in contemporary educational research and practice (White, 2003; Lawton, 2012; Richmond, 2018).

The curriculum defines the planned learning experiences offered to students, encompassing the subjects, topics, content, and learning objectives that students are expected to engage with during their education. The development and implementation of curricula are complex processes influenced by various factors, including national and local policies, educational theories, social and cultural influences, stakeholder engagement, and research evidence (Voogt & Roblin, 2012). Governments typically establish curriculum frameworks that outline core subjects, learning objectives, and assessment guidelines, which can be adapted by educational authorities or individual schools to suit specific needs and contexts, leading to significant variability across education systems (Voogt & Roblin, 2012). Different educational philosophies, such as progressivism or constructivism, shape the emphasis on specific skills, subject areas, and teaching methods within curricula (Harden, 2001). Moreover, societal needs, technological advancements, and cultural values play a crucial role in determining curriculum content and focus, as seen in the current emphasis on digital literacy skills reflecting the importance of technology in today's world (Nordin &

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Sundberg, 2020). Teachers, parents, and community members also influence curriculum development and implementation, while student feedback should ideally guide adjustments to ensure relevance and engagement (Hawkins et al., 2015). Educational research findings on effective teaching methods and learning outcomes also inform curriculum design, resource selection, and activity planning (Davis & Harden, 2003). The discourse on curriculum richness is further enriched by discussions on formal (explicitly planned and documented) versus informal (incidental) curricula, as well as debates on the balance between standardization and flexibility in curricula and the level of teacher autonomy in shaping classroom experiences (Lynch, 2014).

It is important to consider curriculum development as an ongoing process responding to factors such as student needs, emerging technologies, and societal changes, which can necessitate revisions and updates to ensure the curriculum remains relevant and effective. Change and innovation in education, including the introduction of STEAM practices, are integral parts of this process. Simultaneously, rigid standardized curricula can suffocate innovation, while flexible frameworks with space for teacher adaptation open doors for exploration and experimentation (Koirala, 2023).

Taking into account the nature of STEAM practices as discussed further above, conditions and requirements for the integration of STEAM in the school curriculum are shaped by the fact that STEAM education as envisioned represents a dynamic paradigm shift, weaving together science, technology, engineering, arts, and mathematics towards affording creative, collaborative, engaging, and inclusive learning experiences. Integrating STEAM education into the school curriculum therefore requires the foregrounding of priorities discussed in detail in deliverables D4.1 and D2.2, such as fostering interactivity and collaboration, embracing student ownership, promoting creativity, offering problem solving-based, authentic and engaging learning experiences connecting students to the real world and aiming beyond the mere development of cognitive skills, as well as ensuring inclusivity and equity, all of which synthesise an educational approach that empowers students to become innovative, responsible, and engaged citizens of the 21st century. Thus, based on the conceptualisations and analyses from the previous stages of the Road-STEAMer project, we can say that a 'STEAM-friendly' curriculum needs to include the following features:

- **Arts as catalyst:** The curriculum should integrate artistic practices and expression into STEAM in ways that empower students to create, express themselves, and

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connect across disciplines in innovative ways, effectively. Embracing the arts should transcend mere illustration, with arts becoming catalysts for creativity, innovation, and connection-making, fostering divergent thinking and empowering students to communicate their ideas.

- **Embracing multiple pathways to knowledge and unlearning:** The curriculum should encourage multiple pathways to knowledge acquisition, including through exploration and experimentation, encouraging unlearning of preconceived notions, and promoting flexible thinking through diverse learning modalities.

- **Playfulness and flow:** The curriculum should foster a joyful and engaging learning environment where students experience the 'flow' of creative activity. This can be achieved through means such as playful learning elements and open-ended exploration, thus generating intrinsic motivation.

- **Developing a spectrum of thinking:** While intellectual skills like critical and system thinking are essential, STEAM education should go beyond, integrating opportunities for creative, divergent and convergent thinking and metacognition, thus fostering well-rounded learners equipped for the complexities of the 21st century.

- **Problem-solving as a creative process:** The curriculum should move beyond formulaic problem-solving approaches, by incorporating open-ended exploration, hands-on design and production, encouraging students to approach problems creatively and collaboratively.

- **Student ownership and inquiry:** The curriculum should move beyond pre-defined problems and solutions, encouraging student choice, ownership, and active exploration of real-world challenges through hands-on design, production, and inquiry-based learning.

- **Addressing cutting-edge issues:** The curriculum should integrate real-world challenges such as climate change or social justice issues to provide context for learning and, importantly, to encourage students to see the impact of their knowledge and skills on the world around them.

- **Civic engagement and entrepreneurship:** The curriculum should connect STEAM learning to real-world applications that address community needs by promoting civic engagement or encouraging entrepreneurship.

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- **Broadening interests and representation:** The curriculum should aim at attracting a wider range of learners through the integration of arts into STEAM, making it more inclusive than STEM alone, fostering a diverse learning environment where students from all backgrounds feel welcome and engaged.

- **Identity development and empowerment:** The curriculum should create opportunities for students to develop their personal identities within STEAM, including through practices that encourage artistic self-expression, and promote individual meaning-making while addressing issues which are important to the student. It should aim to create opportunities for all students to see themselves as successful STEM and STEAM learners and celebrate diverse perspectives.

- **Diversity in assessment methods:** Assessment focused solely on standardized testing incentivizes adherence to traditional learning and teaching roles and methods. Focusing on continuous formative assessment and incorporating diverse authentic assessment methods can encourage innovative practices such as STEAM, including by helping teachers refine their practice and demonstrate the impact on student learning.

Views on STEAM in the curriculum and relevant challenges

We presented the above elements to participants and sought their views on the relevance of these as conditions for the effective integration of STEAM in education, as well as the degree to which such conditions are easy or difficult to achieve in today's education. Participants agreed on the importance of all of the above learning, teaching and assessment features for the effective integration of STEAM in education. However, integrating STEAM priorities and practices with these characteristics into the existing curricula was perceived as quite challenging.

Participants overall clearly indicated that STEAM has not yet found the position it deserves in the existing curriculum. For instance, Exploratory questionnaire respondents strongly disagreed with the statement that "*STEAM education is adequately represented in the school curriculum*" (Mean=2,35; Median=2; Likert scale: 1=Absolutely disagree - 5=Absolutely agree).

More specifically, achieving interdisciplinarity or transdisciplinarity seems to remain a significant challenge. Participants considered STEAM practices integrating curriculum areas and disciplines which, traditionally, are not connected, as quite difficult to

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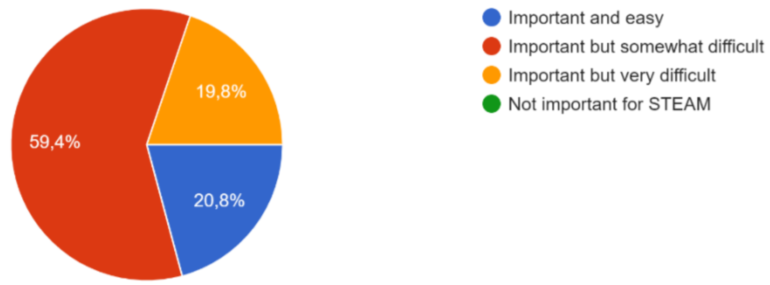
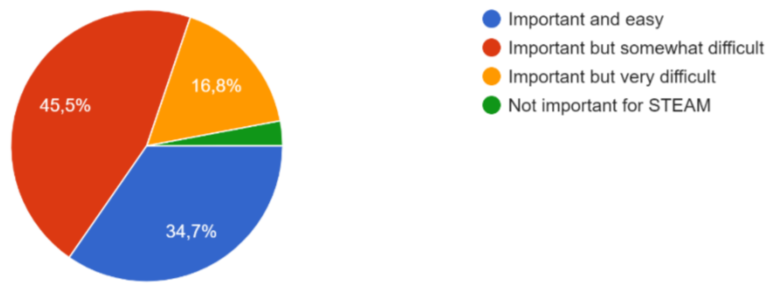
achieve. It is worth noting that the relevant statement in the Final questionnaire was perceived by respondents as one of the most difficult to achieve conditions, with only 1 in 5 respondents characterizing it as “easy to achieve”.

STEAM practices integrating curriculum areas and disciplines which, traditionally, are not connected.
101 απαντήσεις



Providing STEAM practices that involve arts in ways empowering students to express themselves, create and innovate was perceived by participants as a condition which is somewhat easier to achieve compared with other conditions relating to learning. The relevant Final questionnaire statement was marked as “easy to achieve” by about a third of the respondents, although the majority still considers this a challenge (“difficult” of “very difficult”).

STEAM practices involving arts in ways that empower students to express themselves, create, innovate.
101 απαντήσεις



However, according to the responses to the Exploratory questionnaire, the STEAM activities implemented in the educational contexts that participants were familiar with, tend to be related to the Visual Arts rather than the Performing Arts (Mean=3.24 and 2.92 respectively; Median=3 for both; Likert scale: 1=Absolutely disagree -

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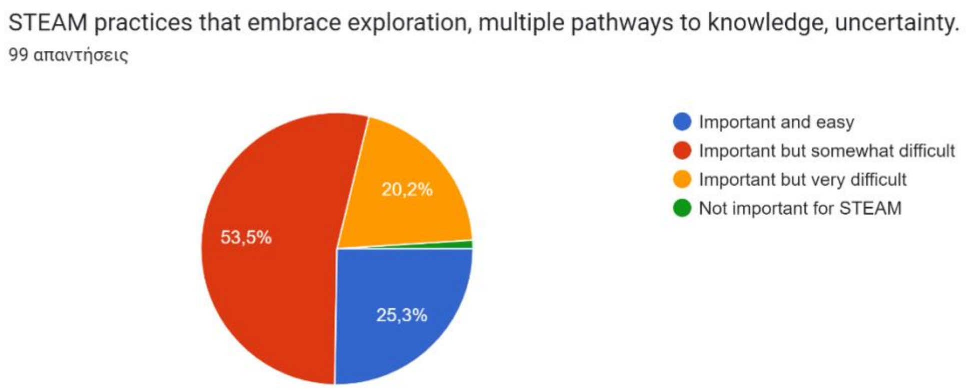
5=Absolutely agree), and the former are more adequately represented in the existing curriculum than the latter (Mean=2.76 and 2.59 respectively; Median=3 for both; Likert scale: 1=Absolutely disagree - 5=Absolutely agree).

Embracing exploration, multiple pathways to knowledge and uncertainty is perceived as a condition for the integration of STEAM in education that is quite difficult to achieve. The relevant Final questionnaire statement was marked as one of the most difficult conditions, with 1 in 5 respondents characterizing it as “very difficult” and 50% considering it “difficult”, and only a quarter of the respondents characterizing it as “easy to achieve”.



Responses to the Exploratory questionnaire indicated very strong agreement about the link between STEAM and creativity in learning, with the relevant statement featuring first in the list of the most agreed upon items (Mean=4,32; Median= 5; Likert scale: 1=Absolutely disagree - 5=Absolutely agree).

What is more, offering STEAM practices that are joyful, engaging and generating intrinsic student motivation, as well as practices fostering student’s active role and ownership of the learning activity, are perceived as comparatively easier to achieve conditions. The relevant Final questionnaire statements were marked as “easy to achieve” by approximately 40% of the respondents.

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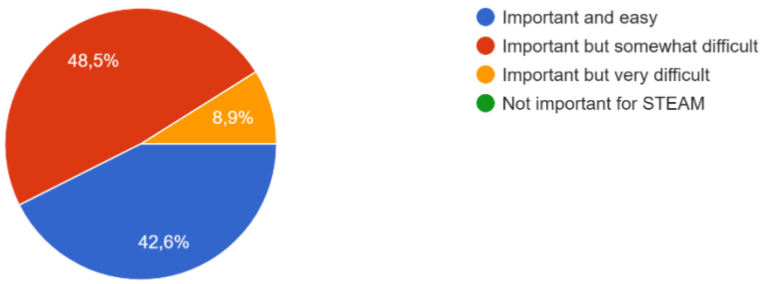
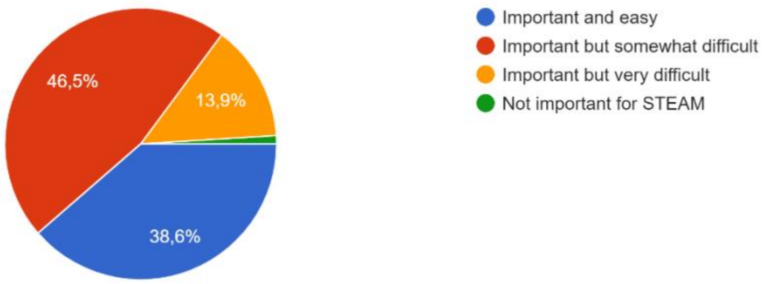
STEAM practices that are joyful, engaging, generating intrinsic student motivation.
101 απαντήσεις

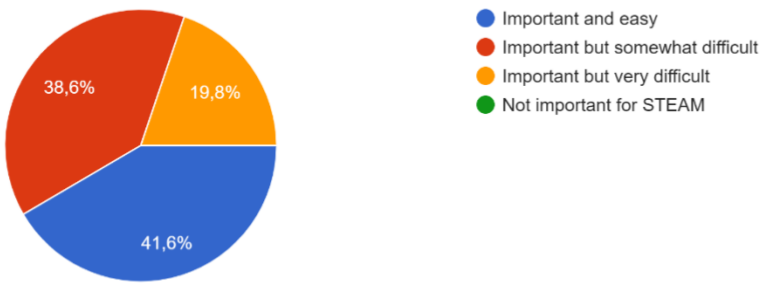


STEAM practices that foster student's active role and ownership of the learning activity.
101 απαντήσεις



Similarly, developing a variety of thinking skills was also perceived by Final questionnaire respondents as one the easier to achieve conditions.

STEAM practices that develop a variety of thinking skills (e.g., critical, creative, systems thinking, metacognitive).
101 απαντήσεις



Further, responses to the Exploratory questionnaire indicated rather strong agreement that STEAM favours the synthesis of thinking with doing and making (Mean=4,08; Median= 4; Likert scale: 1=Absolutely disagree - 5=Absolutely agree). In addition,

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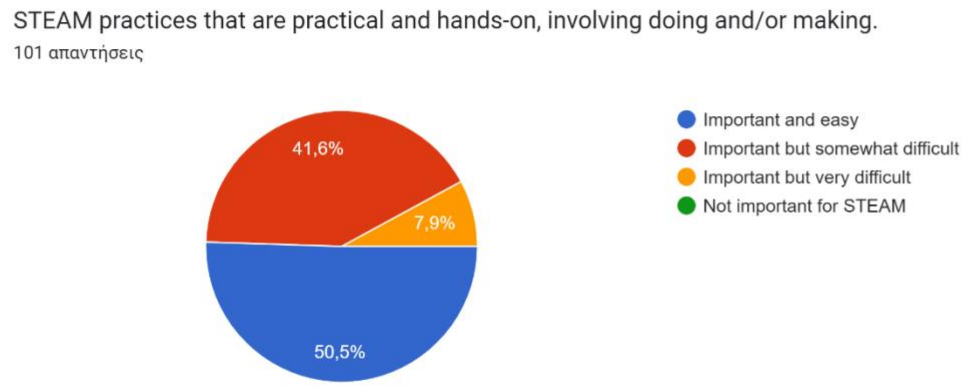
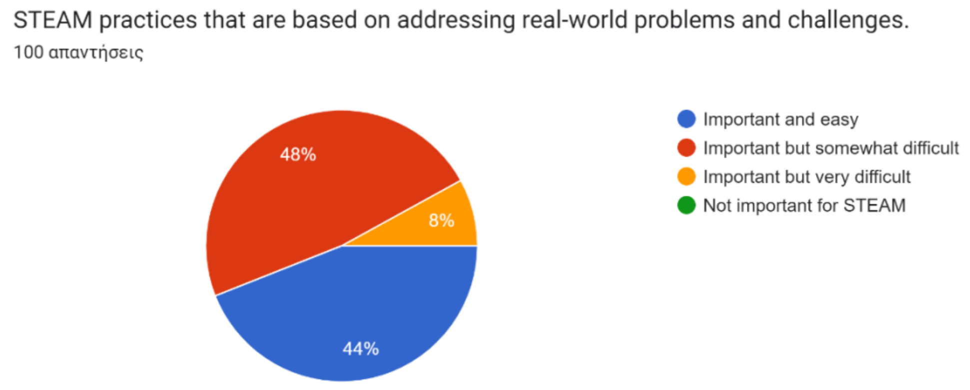
implementing STEAM practices that are practical and hands-on, involving doing and making, is perceived as the easiest to achieve condition relating to learning. The relevant Final questionnaire statement was marked as “easy to achieve” by half of the respondents.



Exploratory questionnaire responses indicated rather strong agreement that STEAM favours the connection of learning with the real world (Mean=4,03; Median= 4; Likert scale: 1=Absolutely disagree - 5=Absolutely agree). In addition, basing STEAM practices on addressing real-world problems and challenges is considered as one of the easier to achieve conditions. The relevant Final questionnaire statement was marked as “easy to achieve” by 44% of the respondents.



However, implementing STEAM practices which specifically address community needs, societal concerns and cutting-edge issues emerges from the Final questionnaire responses as significantly more difficult to achieve. The relevant statement was marked as one of the most difficult conditions, with 1 in 5 respondents

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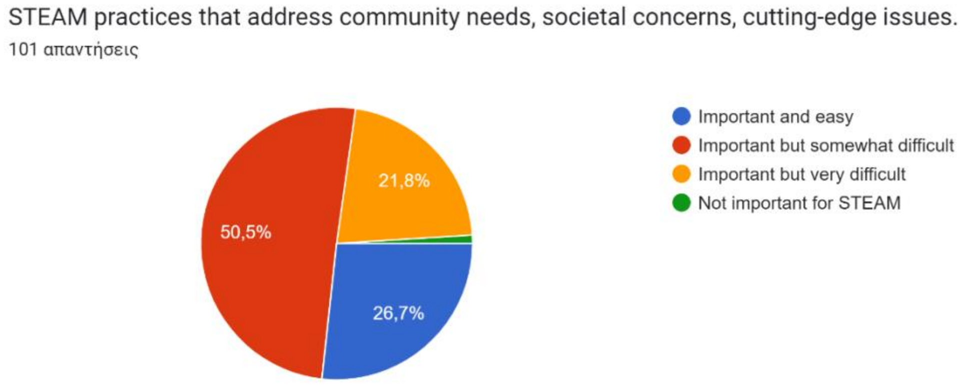
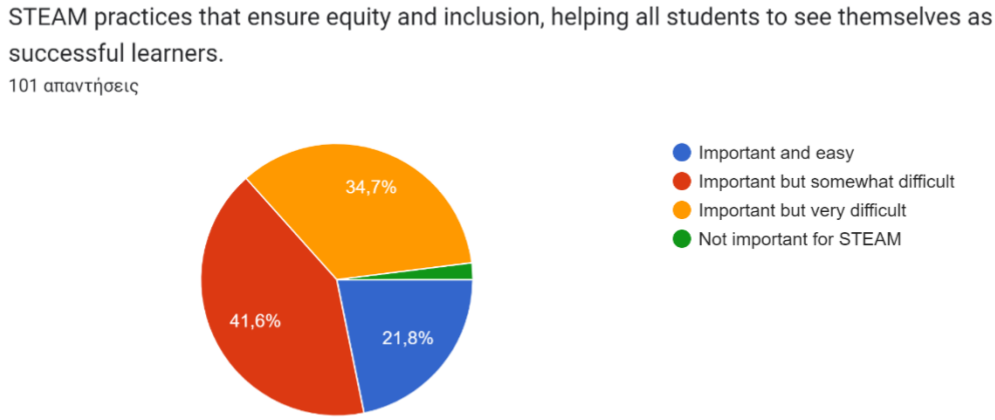
characterizing it as “very difficult” and 50% considering it “difficult”, and only about a quarter of the respondents characterizing it as “easy to achieve”.



Exploratory questionnaire responses indicated strong agreement that STEAM favours the inclusion and empowerment of all students, with the relevant statement featuring second in the list of the most agreed upon items (Mean=4,24; Median= 4; Likert scale: 1=Absolutely disagree - 5=Absolutely agree). However, implementing STEAM practices that ensure equity and inclusion and help all students see themselves as successful learners is not considered easy. As a matter of fact, the relevant statement in the Final questionnaire was perceived by respondents as the condition that is the most difficult of all to achieve, with only 1 in 5 respondents characterizing it as “easy to achieve”, and a third of the respondents marking it as “very difficult”.



Similarly, empowering students to develop their identities and personal meaning-making is perceived as quite difficult to achieve. The relevant Final questionnaire

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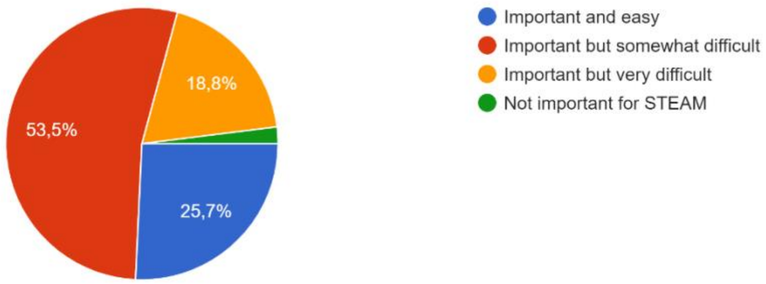
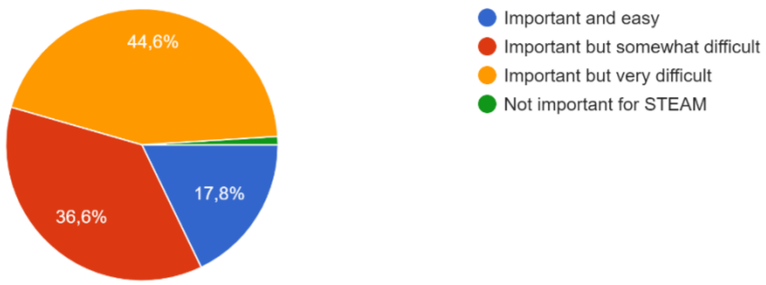
statement was marked as one of the difficult conditions to achieve, with only 25% of the respondents characterizing it as “easy to achieve”.

STEAM practices that empower students to develop their identities and personal meaning-making.
101 απαντήσεις



Learning assessment practices that go beyond traditional testing, to cover aspects such as student engagement, collaboration and wider competence development emerges from the responses as a condition for STEAM that is very difficult to achieve. The corresponding statement in the Final questionnaire was perceived by respondents as one of the most difficult to achieve conditions, with about 18% of the respondents characterizing it as “easy to achieve”, and about 45% finding it as very difficult. On the other hand, the use of learning assessment practices to help in the ongoing evaluation and improvement of educational practices is perceived as slightly easier, but still a significant challenge.

Learning assessment practices that go beyond traditional testing, to cover aspects such as student engagement, collaboration, wider competence development.
101 απαντήσεις



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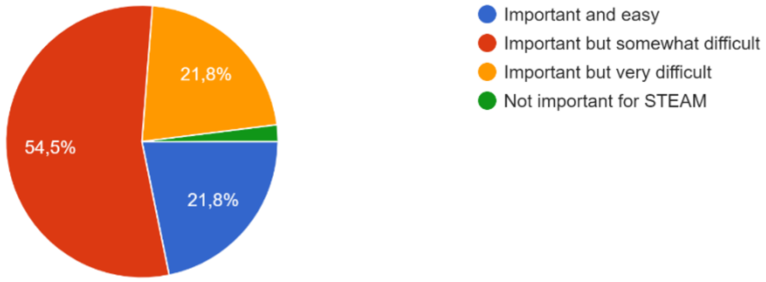
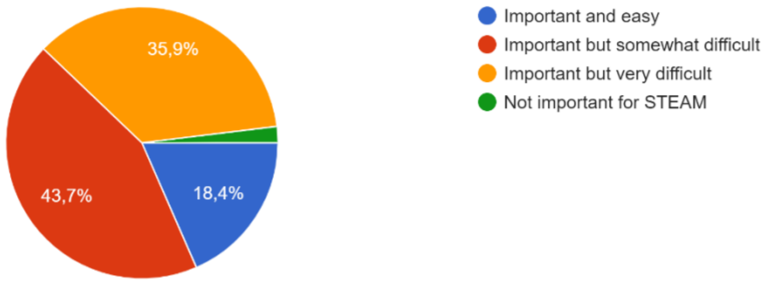
Learning assessment practices that help in the ongoing evaluation and improvement of educational practices.
101 απαντήσεις



Final questionnaire items focusing on wider curriculum frameworks and educational policy reveal that the condition of curriculum flexibility allowing for innovative practices is considered as very difficult to achieve, closely followed by teachers being able to make independent teaching and assessment choices within general curriculum frameworks and guidelines. Notably, respondents consider it as relatively easier to have STEAM formally recognized as part of the curriculum.

Teachers making independent teaching and assessment choices, within general curriculum frameworks and guidelines
103 απαντήσεις



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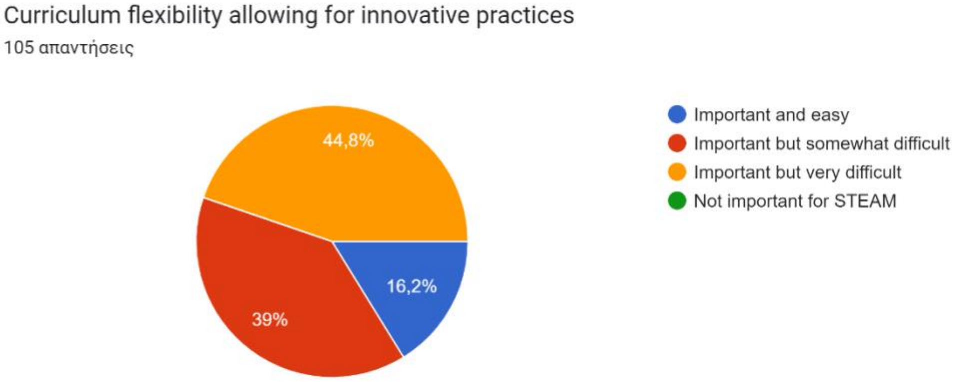

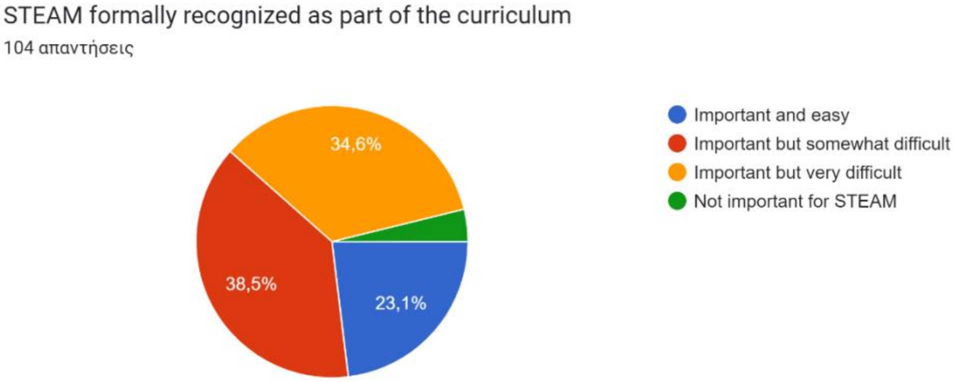

Finally, when asked about their preference for the position of STEAM within the existing curriculum, Final questionnaire respondents show a clear, very strong preference for STEAM practices integrated across the curriculum, with more than 80% preferring or strongly preferring this, compared to STEAM as a separate curriculum area which is not preferred by at least half of the respondents. In addition, if STEAM practices were to be integrated mainly in STEM curriculum areas or mainly in arts and humanities curriculum areas, data reveal a tendency towards a stronger preference for the former. This, however, is not conclusive and could be attributed to the background of the respondents, as well as partly to the cultural roots of STEM with which STEAM is often associated (Colucci-Gray et al., 2019).

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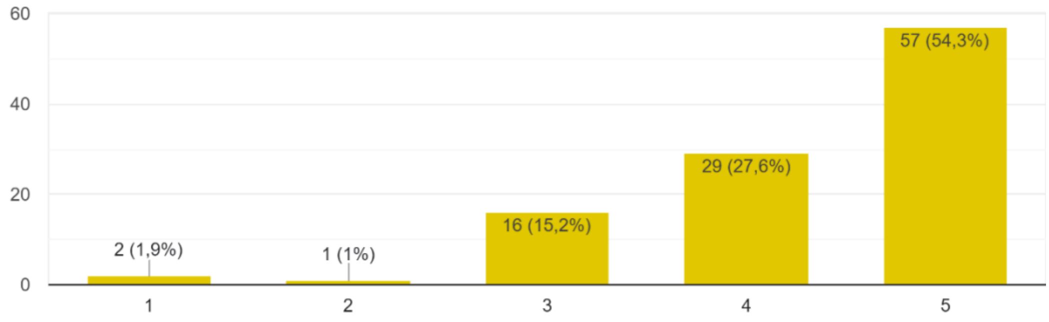
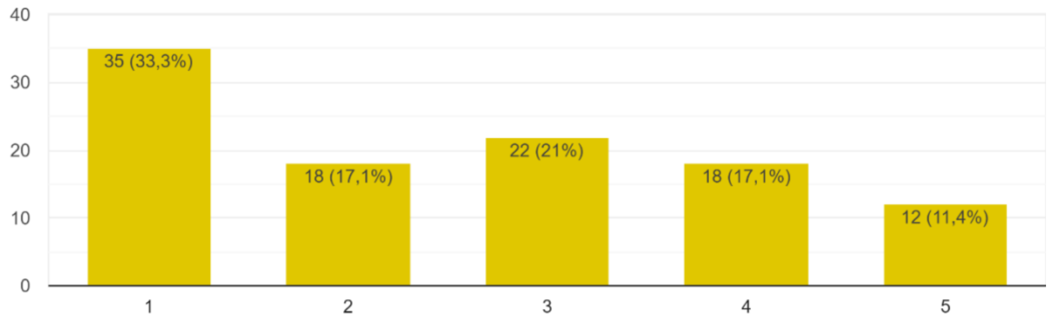
STEAM practices integrated across the curriculum
105 απαντήσεις

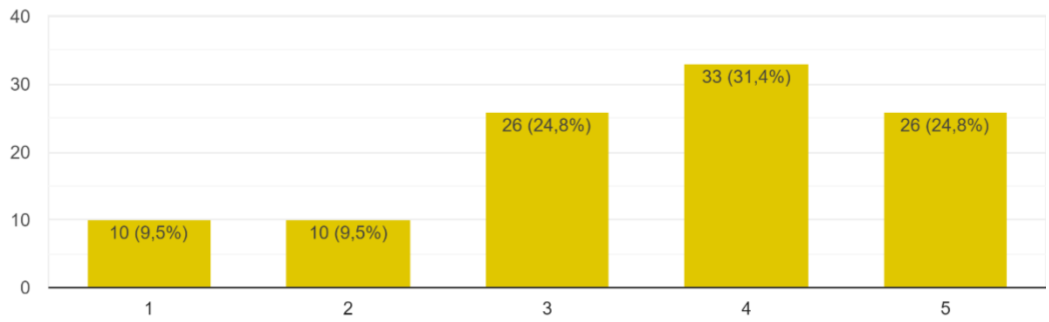


STEAM as a separate curriculum area
105 απαντήσεις



** Likert scale: 1=Not preferable - 5=Strongly preferred*

STEAM practices integrated mainly in STEM curriculum areas (science, technology, engineering, mathematics)
105 απαντήσεις



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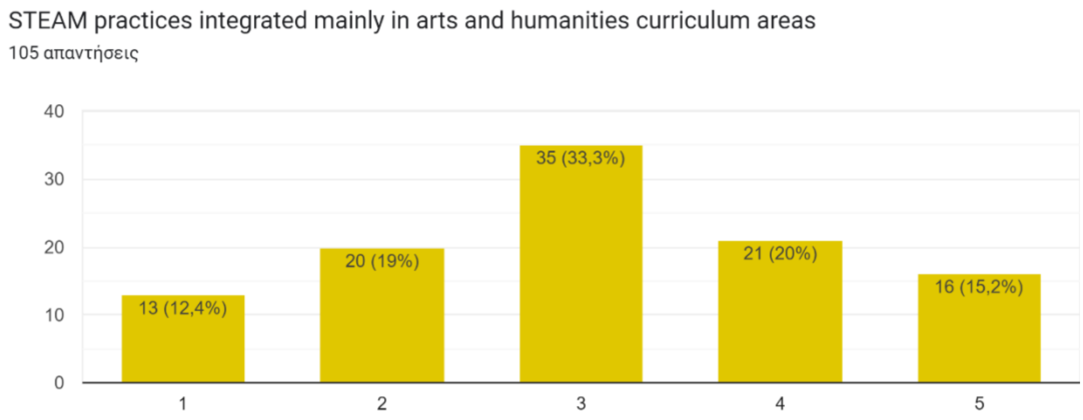

** Likert scale: 1=Not preferable - 5=Strongly preferred*

It should be noted that the above are broad considerations, and successful implementation of STEAM integration in the curriculum requires exploring and addressing specific context-dependent factors, as well as ongoing research to understand the nuances and impacts of STEAM education in various settings. For this reason, based on the discussions held with teachers in the workshops, we conducted a deeper analysis of some examples of implementing STEAM in the existing school curriculum. This is presented in section 3 of this report.

2.2.2 Teachers: influential beyond the individual level

Teachers drastically influence the uptake of an educational innovation such as the introduction of STEAM practices beyond the individual level of their own practice. While individual teacher characteristics undoubtedly play a significant role in the uptake of educational innovations and of STEAM education in particular, a deeper understanding requires going beyond mere demographic markers, examining teachers within the complex system of education, where teacher's individuality is intrinsically intertwined with the educational context (Baharuddin et al., 2019; Zainal and Matore, 2021).

Workshop discussions focused on how teacher's deeply held beliefs about teaching and learning shape their receptivity to any educational innovations (Gibson and Dembo, 1984; Brownell and Pajares, 1999). For instance, it was noticed that STEAM pedagogies such as those described in Road-STEAMer may resonate more with teachers who value inclusivity and diversity.

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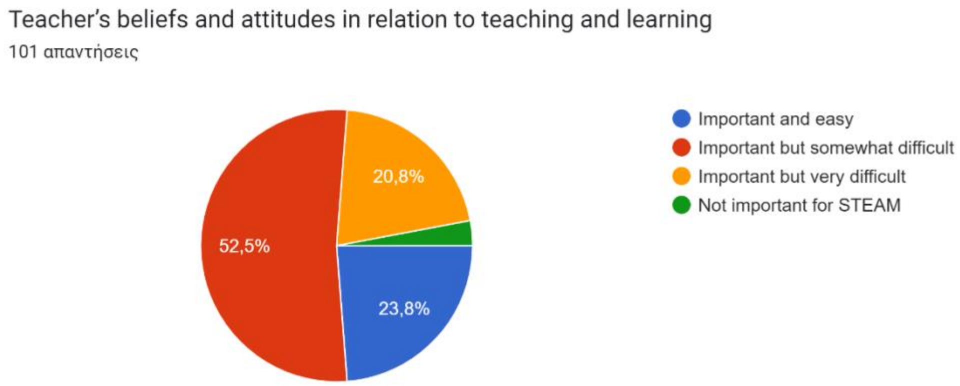
Generally, teachers' appropriate beliefs and attitudes in relation to teaching and learning were perceived as a condition for the integration of STEAM in education that is rather difficult to achieve. The relevant Final questionnaire statement was marked as one of the most difficult conditions, with about 21% of the respondents characterizing it as "very difficult", about 52% considering it "somewhat difficult", and only 24% characterizing it as "easy to achieve".



In addition, workshop participants discussed how teachers' knowledge and prior experiences, including past successes or failures with innovations, may influence their openness to the adoption of STEAM practices. Relevant Final questionnaire responses reveal that teacher's familiarity with other areas of the curriculum beyond their own main area(s) of expertise, as well as teacher's belief in their own ability to apply STEAM in practice (i.e. self-efficacy) are significant challenges. Overall, they are two of the conditions for STEAM integration in education that are considered by Final questionnaire respondents as most difficult to achieve. There is also a marked difference be tween these and other conditions studied relating to teachers' competence, such as their familiarity with educational uses of technology, which is deemed as an easier to achieve condition.

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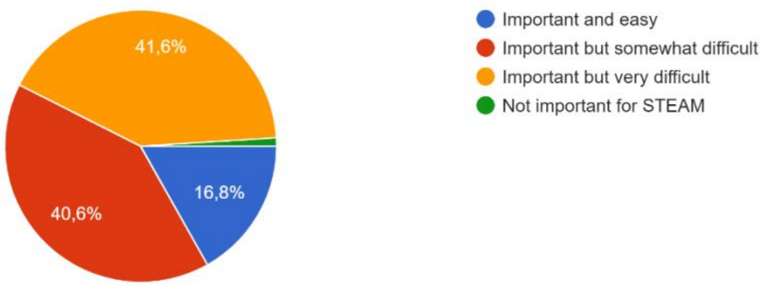
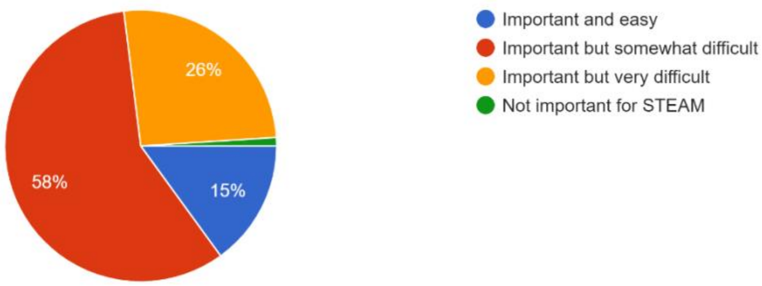
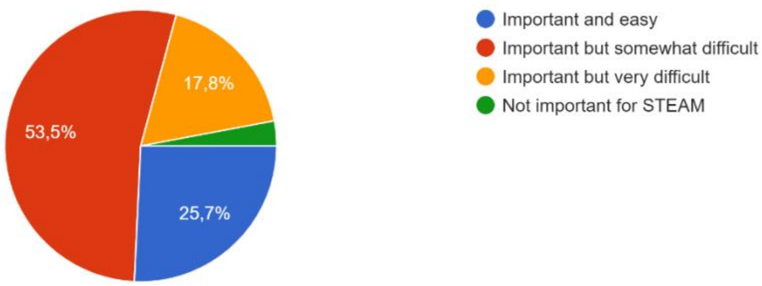
Teacher's familiarity with other areas of the curriculum beyond their own main area(s) of expertise
101 απαντήσεις



Teacher's belief in their own ability to apply STEAM in practice
100 απαντήσεις



Teacher's familiarity with the use of technology in educational practice
101 απαντήσεις



Workshop discussions also particularly emphasised the importance of teachers feeling valued and trusted to make pedagogical decisions, which can fuel their intrinsic motivation in exploring and implementing innovations that align with their personal goals and vision for student learning. However, Final questionnaire responses reveal that teacher's freedom to decide and act autonomously, teacher's ownership and personal investment in STEAM practices and initiatives, as well as teacher's being able

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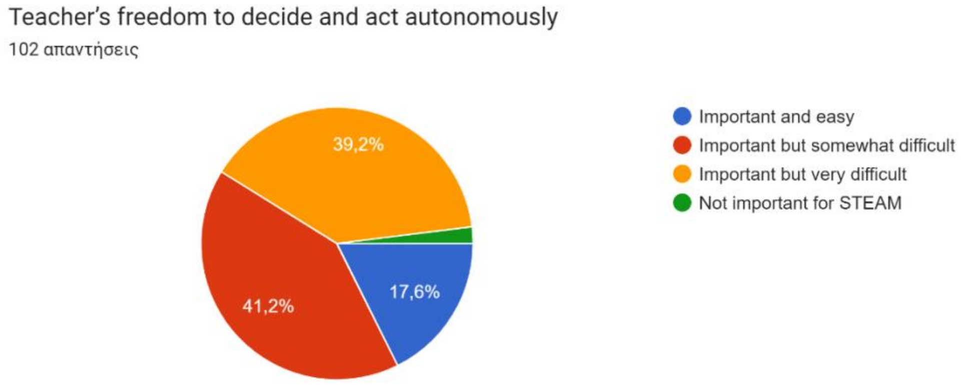
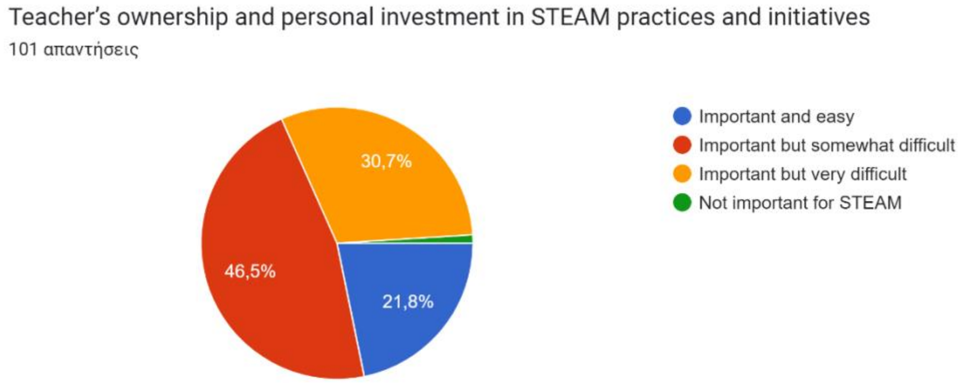
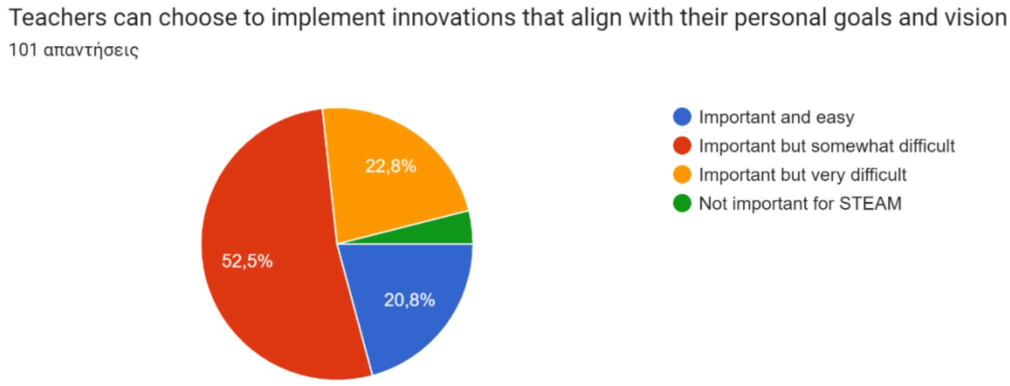
to choose to implement innovations that align with their personal goals and vision, are deemed as three of the more difficult to achieve conditions.







Teacher agency (Priestley et al., 2015; Calvert, 2016) is a powerful concept that can help reveal some of the key aspects of the teacher's role for the introduction of STEAM in education. It shifts the focus to teacher's capacity to act purposefully and

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autonomously in their professional lives, being able to make informed decisions, take action, and solve problems, and in this way contribute to their own growth and that of their students. Based on insights offered in the literature on teacher agency (Matikainen et al., 2018), discussion in the workshops concluded that fostering teacher agency in STEAM education encompasses key aspects such as the following:

- **Autonomy:** Teachers can make independent choices about curriculum, pedagogy, and assessment in adopting or developing STEAM practices, within the general frameworks and guidelines provided by the educational system.
- **Reflection:** Teachers can think about their STEAM practice critically, analyze data and the experience, and make informed changes.
- **Collaboration:** Teachers can work with colleagues to share expertise, develop resources, and improve their STEAM practices.
- **Advocacy:** Teachers can represent students' needs and interests addressed through STEAM, within the school system.
- **Leadership:** Teachers can take initiative, inspire others, and drive positive change in education through STEAM.

Workshop participants confirmed that fostering teacher agency offers multiple benefits for the school community, which can support the introduction of STEAM practices. Such gains include increased teacher satisfaction and motivation, enhanced student learning and engagement, improved school climate and culture, more innovative and responsive teaching practices, as well as greater professional development and teachers' self-efficacy empowering teachers as agents of change (Priestley et al., 2013).

Nevertheless, securing such conditions in today's education was not considered easy by our informants. For instance, teacher's role as a change agent, actively driving positive change in education was deemed by Final questionnaire respondents as one of the most difficult to achieve conditions, followed closely by teacher's job satisfaction and motivation.

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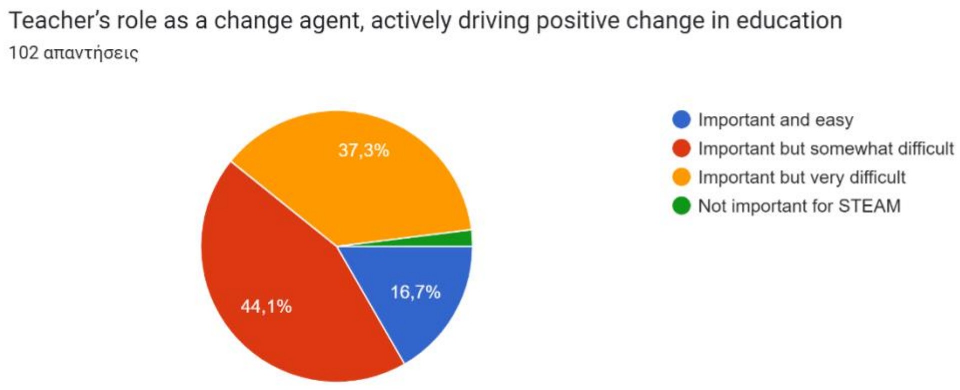

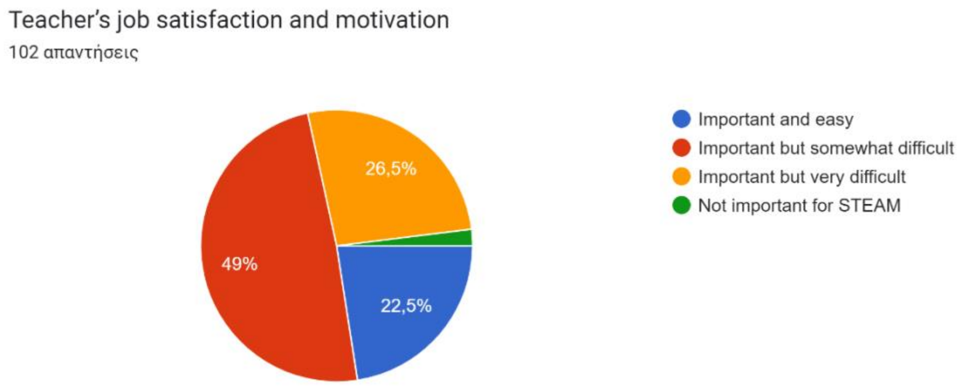

Workshop discussions further pointed to that fact that fostering teacher agency requires addressing challenges which are inherent to schools and educational systems, such as top-down policies, standardized testing, limited resources and time, and an overall unsupportive school culture and climate as manifesting, for instance, in lack of trust and autonomy from leaders. These considerations are discussed in detail further below, in the section on school climate, culture, organisation and leadership (section 2.2.3).

Most importantly, the effective introduction of educational innovations, including STEAM, entails a degree of teacher transformation (Silk, 2021). Workshop participants agreed that the traditional role of the teacher as instructor must evolve, as STEAM practices require facilitators, guides, and advisors who empower student-led learning, encourage inquiry, and provide constructive feedback. Professional development opportunities equipping teachers with these skills are vital, as discussed further below. However, the shift in teacher's role from instructor to facilitator of student-led learning was considered by Final questionnaire respondents as one of the most difficult to

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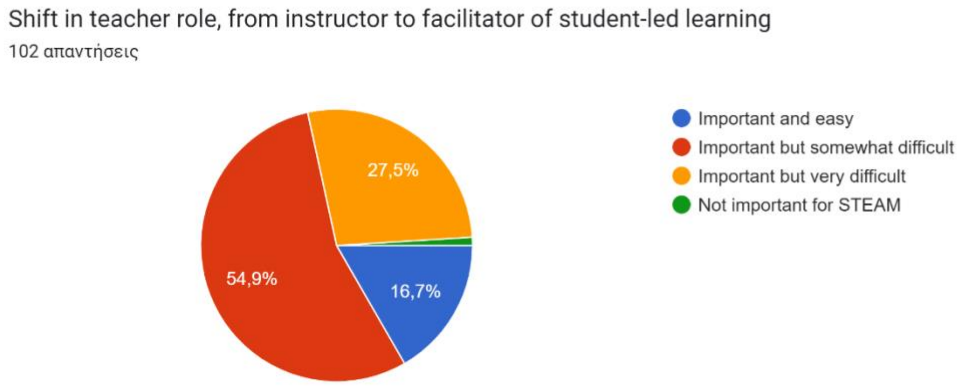
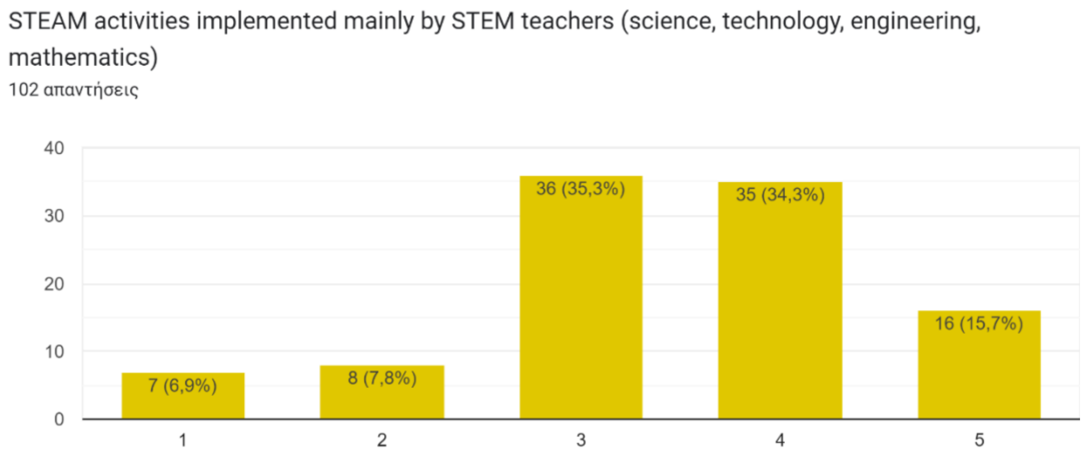
achieve conditions, with only 17% of the responses linked to the "important and easy" characterisation.



Finally, we asked our informants who completed the Final questionnaire, to indicate the background of teachers that they would prefer to implement STEAM based on what they consider most appropriate for the integration of STEAM in today's education. There seems to be a slight preference for STEAM activities to be implemented mainly by STEM teachers rather than by arts and humanities teachers. This, however, is not conclusive and could be attributed to the background of the respondents, as well as partly to the cultural roots of STEM with which STEAM is often associated (Colucci-Gray et al., 2019). Nevertheless, it is very clear that Final Questionnaire respondents strongly prefer that STEAM activities will be implemented by <u>all</u> teachers, as well as, to a lesser extent, by teachers with a STEAM specialization.



** Likert scale: 1=Not preferable - 5=Strongly preferred*

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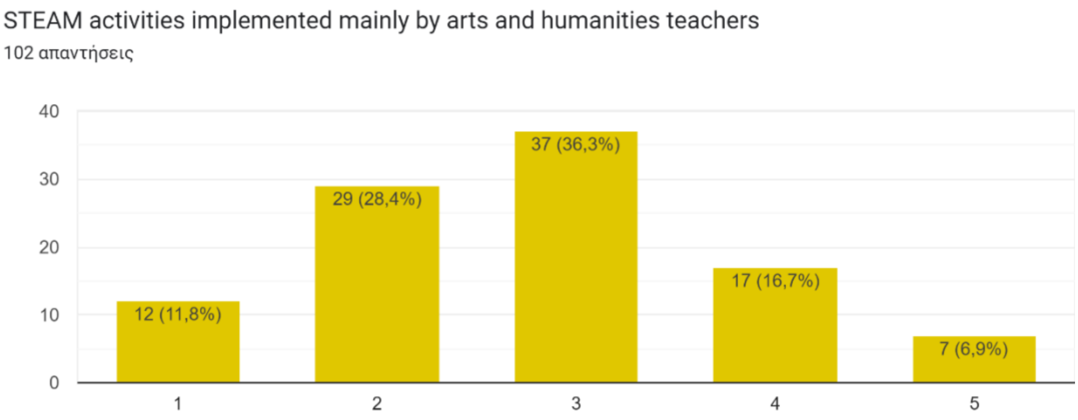

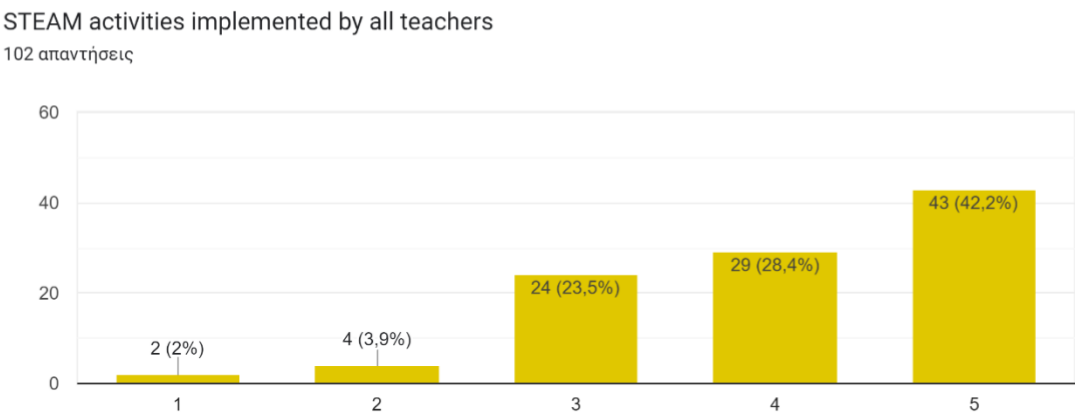

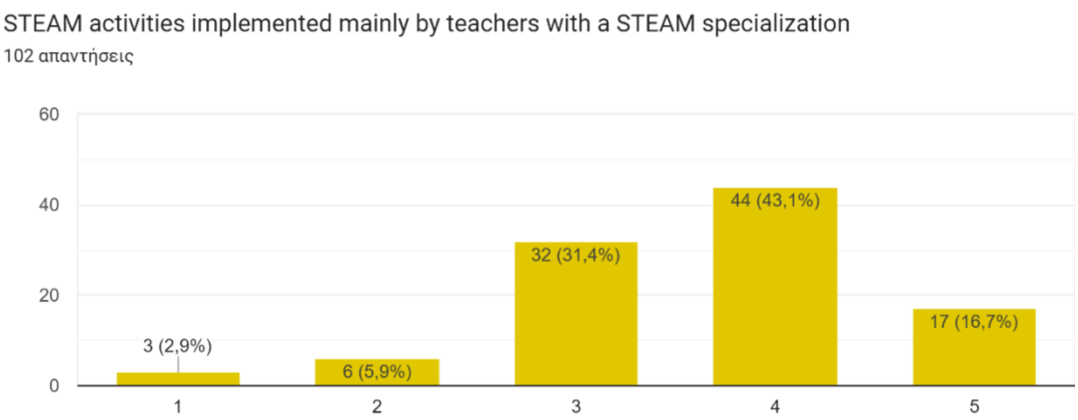

** Likert scale: 1=Not preferable - 5=Strongly preferred*

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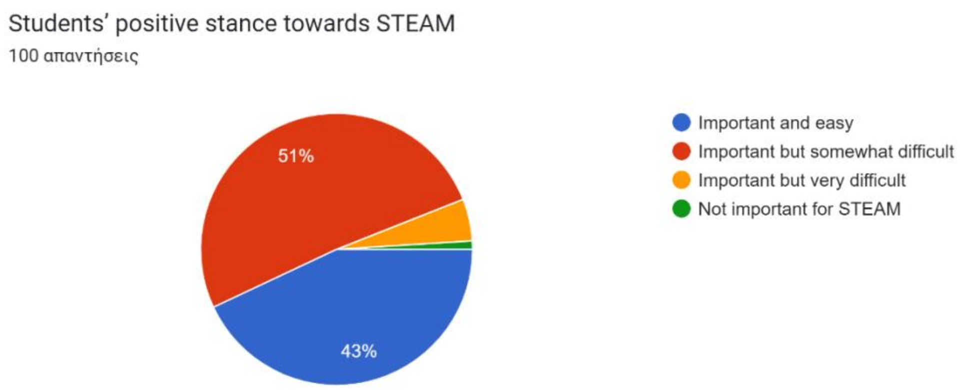
2.2.3 School climate, culture, organisation and leadership

While teachers play a pivotal role in implementing educational innovations, the soil in which these innovations flourish or wither is cultivated by school structures, organisation and leadership. In addition, it is affected by the overall school climate and culture, including students' background and dispositions. Considerations about school climate, culture, organisation and leadership were extensively discussed in the workshops and covered by several questionnaire items. The relevant results are presented in the following sections.

Students' readiness as a factor

In relation to students, achieving their positive stance towards STEAM seems to be a relatively easier to achieve condition. The relevant Final questionnaire statement was marked as "easy to achieve" by 43% of the respondents.



In addition, among the different student-related factors that we studied, Final questionnaire responses indicated that those which are more likely to play a role for the effective integration of STEAM in education are predominantly students' previous learning experiences, and, less strongly, students' previous knowledge and academic achievement. On the other hand, responses about the impact of students' socioeconomic background were quite ambivalent.

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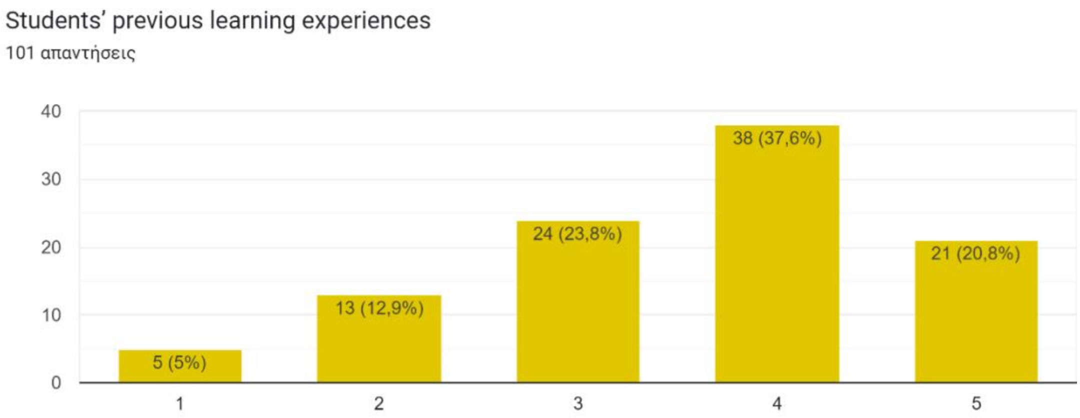

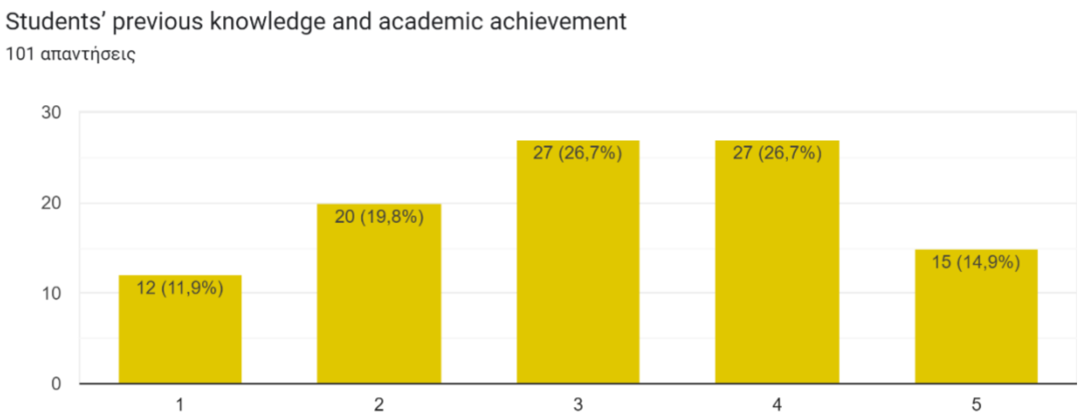

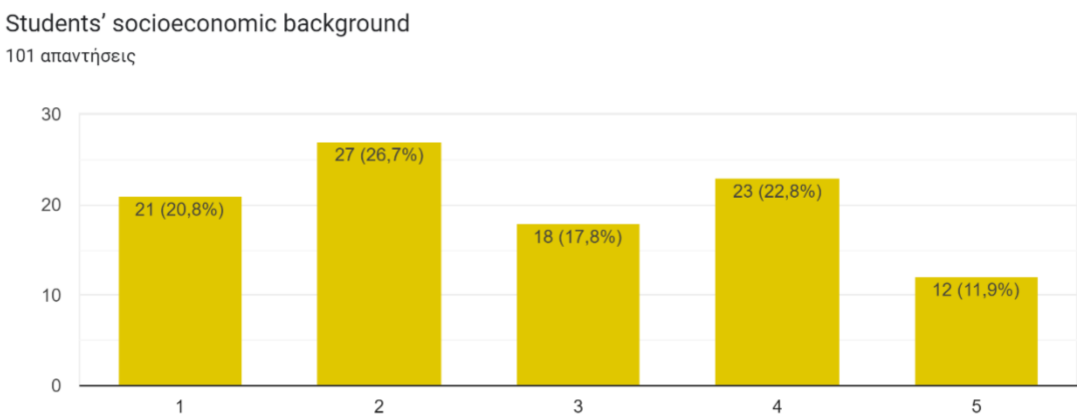

** Likert scale: 1=Not important - 5=Very important*

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School leadership and climate for STEAM

Based on insights from literature on educational leadership and its interplay with educational innovation (Rashid et al., 2011; Peurach et al., 2022; Rikkerink et al., 2016; Kilag et al., 2024), in the workshops we discussed the role of school leadership and culture in the efforts to integrate STEAM in education. It became evident that integrating STEAM approaches in education demands a transformation beyond the classroom, including proactive and visionary leadership that will create the organizational conditions necessary for STEAM to flourish. The innovative nature of STEAM practices requires re-thinking school cultures and organization in ways that will create a more receptive environment for educational change affording the introduction of STEAM, e.g. by dismantling institutional silos, embracing a culture of collaboration and innovation, and thus eventually significantly influencing teacher buy-in and successful implementation.

In addition, discussions about the role of school leadership for the integration of STEAM in education considered an overarching shift from authority to a collaborative vision. It was stressed by participants that models of distributed leadership need to be employed as traditional top-down leadership approaches struggle to capture the dynamism of STEAM. Through distributing leadership roles, schools could empower teachers by encouraging shared decision-making, collaborative leadership, and ownership and investment in implementing new practices and STEAM initiatives.

Further, in workshop discussions it was particularly stressed that school leaders who articulate a clear vision and set the tone for a growth mindset can cultivate a culture that encourages innovation, risk-taking, and learning from mistakes. It was felt that given the exploratory and experimental nature of many STEAM practices, it is necessary for the school to develop tolerance for uncertainty and a willingness to embrace failure as part of the learning process. Cultivating a trusting environment where teachers feel safe to explore, experiment, fail, and learn fosters an open and innovative school culture affording STEAM initiatives.

However, Final questionnaire responses very clearly demonstrate that today's education realities are far from the above vision for school leadership's active and proactive support for the integration of STEAM in education. Responses to all questionnaire items focusing on school leadership reveal that the relevant conditions are generally perceived as very difficult to achieve.

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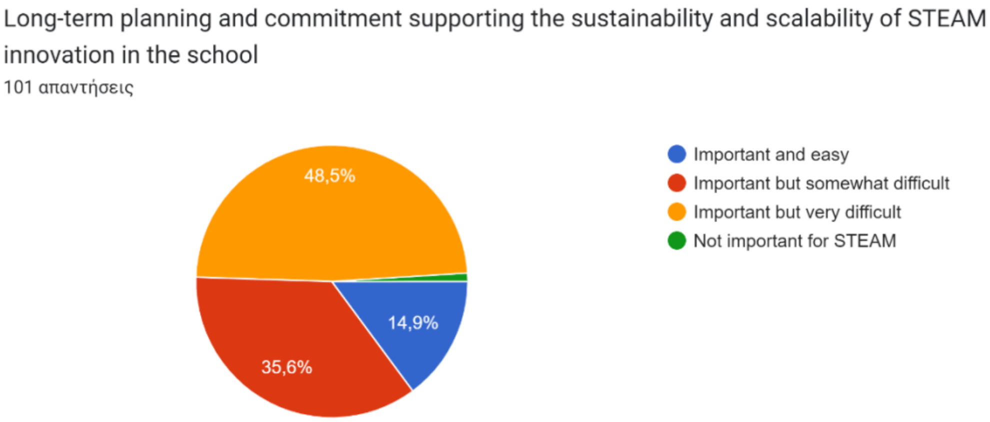
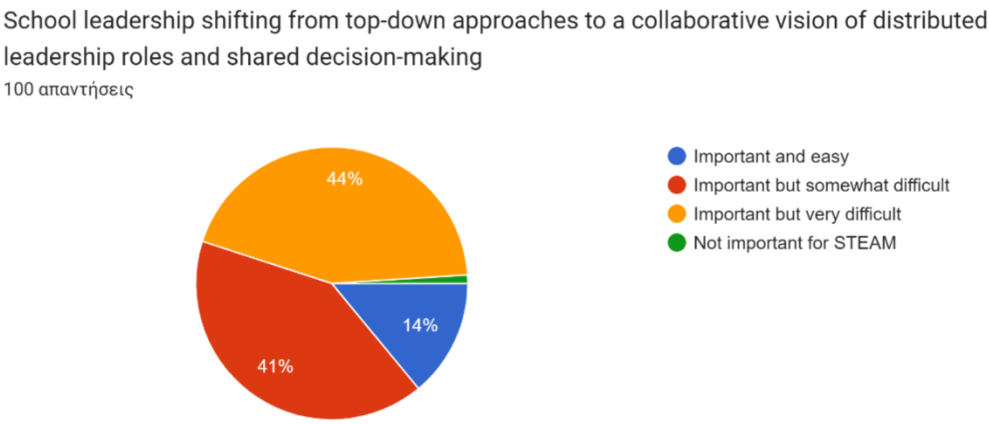
Our informants indicated that among those, the most challenging is long-term planning and commitment that will support the sustainability and scalability of STEAM innovation in the school.



This is closely followed by a shift in school leadership from top-down approaches to a collaborative vision of distributed leadership roles and shared decision-making, as well as by visionary school leadership that will proactively create the conditions for the integration of STEAM, and school leadership supportive of innovative educational practices.



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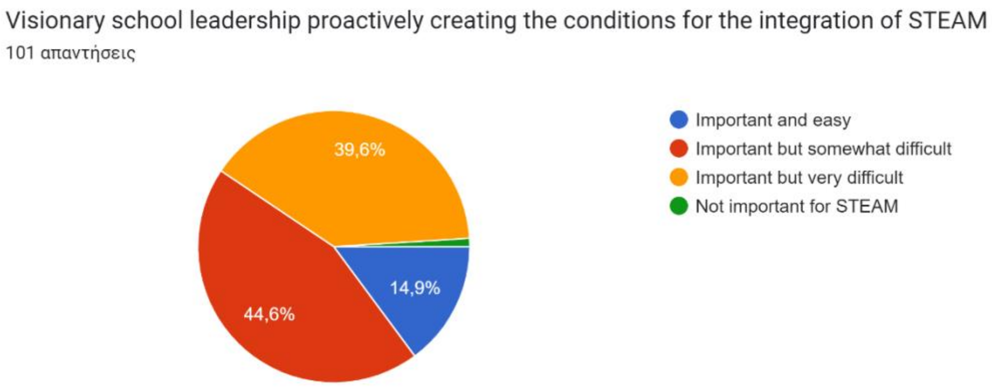

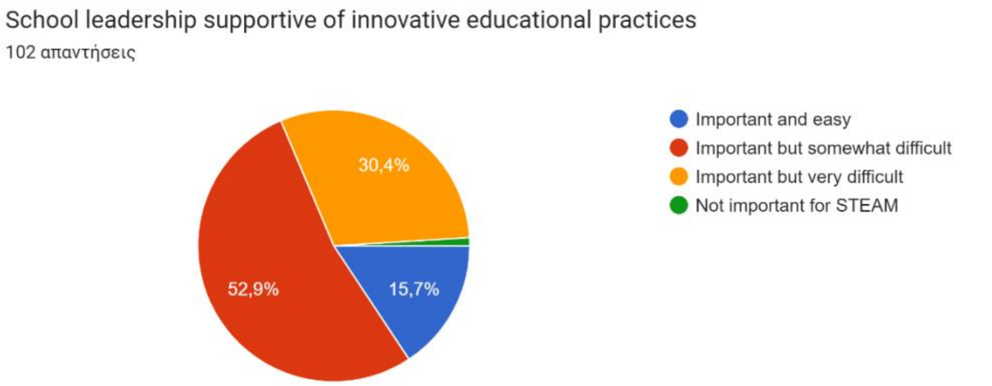

The two leadership-related questionnaire items that are marked by a slightly more optimistic stance are the statements about encouragement of exploration, experimentation, risk-taking, and learning from mistakes, as well as about school leadership trusting teacher autonomy and initiative.

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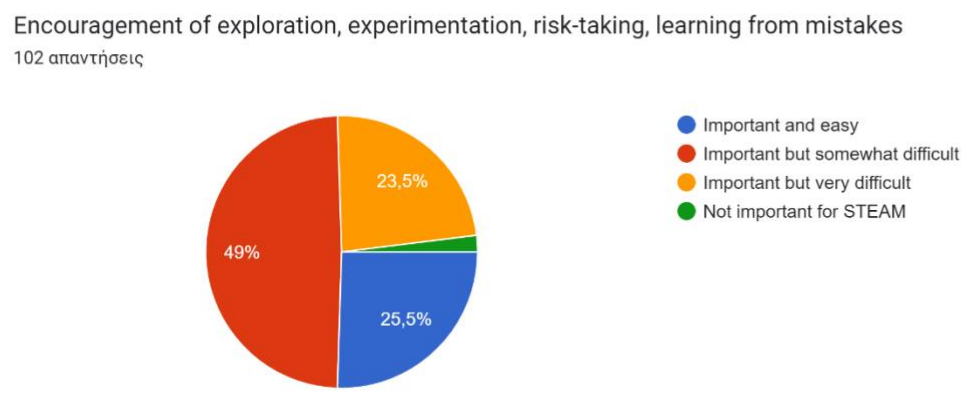

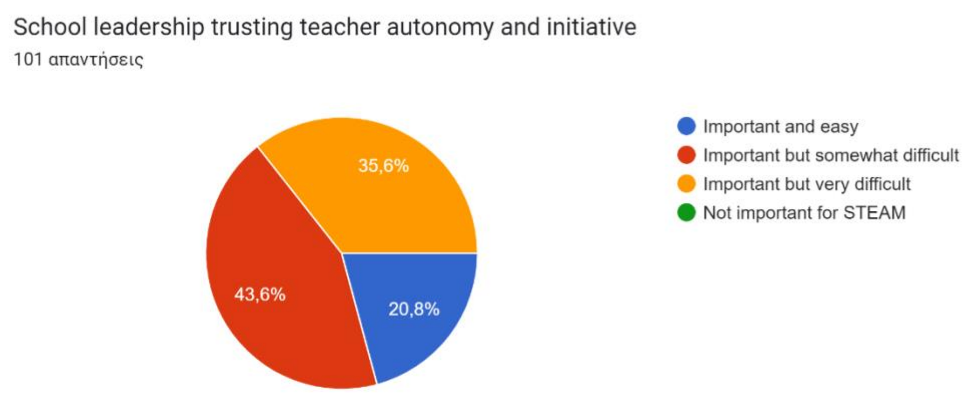

On this background of strong need for more STEAM-friendly school leadership, conditions in schools more generally still do not always appear to be very favourable and encouraging for STEAM. While Exploratory questionnaire respondents were ambivalent about the statement "*My school encourages doing STEAM activities*" (Mean=3,03; Median=3; Likert scale: 1=Absolutely disagree - 5=Absolutely agree), they clearly tended to disagree with the statement "*The conditions for doing STEAM activities at my school are favourable*" (Mean=2,78; Median=3; Likert scale: 1=Absolutely disagree - 5=Absolutely agree). The traditional character of education and fear of change seem to be important factors contributing to this. According to the responses to the Barriers questionnaire, fear of change and resistance to new approaches are the third most important barrier to the integration of STEAM in education (Mean=3,95; Median=4; Likert scale: 1=Least important barrier - 5=Most important barrier), followed closely by the traditional character of the educational paradigm, which is ranked fourth (Mean=3,84; Median=4; Likert scale: 1=Least important barrier - 5=Most important barrier).

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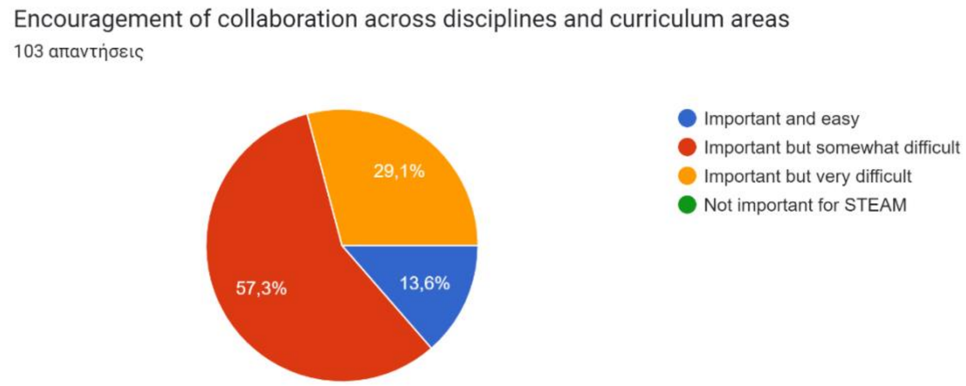
While workshop participants recognized that specific organizational and leadership needs for the integration of STEAM in education will vary depending on the context, resources, and existing structures in each educational system and school, in the following sections we summarise some overarching messages that emerged from the workshop discussions on ways to enable the effective implementation of STEAM across diverse organizational settings.

Collaborative and equitable culture

Workshop participants confirmed that cultivating an environment that fosters collaboration and communication across disciplines in the school is crucial for the development of STEAM practice. This requires fostering teamwork and valuing diverse perspectives, at all levels: among students, between students and teachers, among teachers, as well as in the interaction of the school with external partners and stakeholders.

However, the encouragement of collaboration across disciplines and curriculum areas emerges from Final questionnaire responses as a one of the most difficult to achieve conditions linked to school climate and culture.



More generally, effectively implementing collaboration across the school community and with the surrounding environment does not appear to be easy. On the one hand, responses to the Exploratory questionnaire indicated rather strong agreement that STEAM favours better collaboration during learning (Mean=4,03; Median= 4; Likert scale: 1=Absolutely disagree - 5=Absolutely agree). On the other hand, however, Final questionnaire responses revealed a marked difference in relation to how participants felt about whether it is easy or difficult for STEAM practices to foster collaboration. While it is perceived by the majority as easy to foster collaboration among students,

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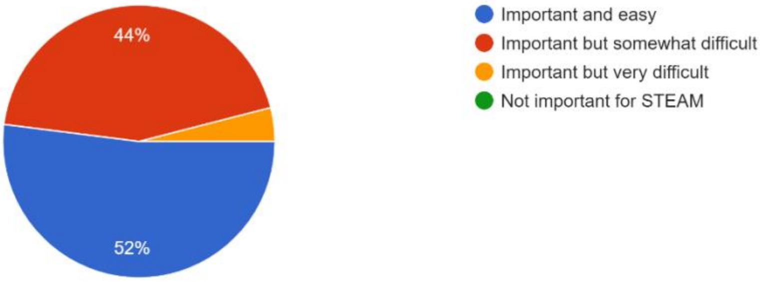
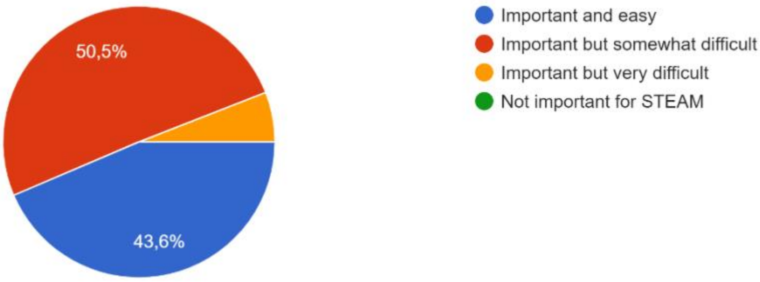
half of the respondents consider it somewhat difficult to foster collaboration among students and teachers. What is more, it is deemed far more difficult to foster collaboration among students, teachers and actors from outside school.

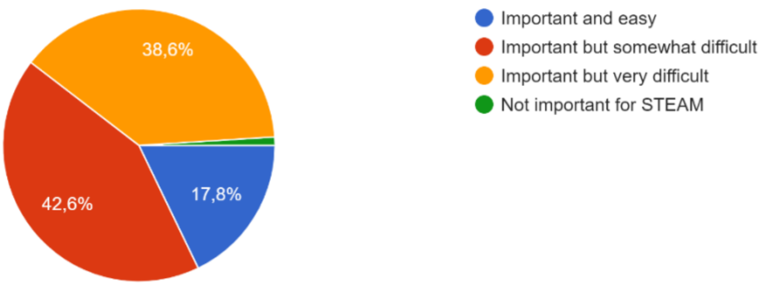
STEAM practices that foster collaboration among students.
100 απαντήσεις



STEAM practices that foster collaboration among students and teachers.
101 απαντήσεις



STEAM practices that foster collaboration among students, teachers, and actors from outside school.
101 απαντήσεις



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Workshop discussions also confirmed that teacher collaboration and resource sharing is particularly important, as breaking down disciplinary silos requires strong collaboration among educators. It was felt that sharing expertise, resources, and best practices across disciplines fosters a collective understanding of STEAM principles and facilitates its effective implementation. In addition, participants noted that collaborative planning teams, peer coaching, and professional learning communities can provide fertile ground for sharing ideas and refining innovative practices, as will be discussed in detail further below in the section on teacher support and professional development (section 2.2.4).

However, collaboration among teachers does not seem to be without its challenges. In the Exploratory questionnaire, respondents tended to disagree with the statement “My colleagues are available to collaborate on the development and implementation of STEAM activities.” (Mean=2,78; Median=3; Likert scale: 1=Absolutely disagree - 5=Absolutely agree). Nevertheless, it is encouraging that teachers sharing expertise, good practices, and resources with their colleagues was deemed by Final questionnaire respondents as one of the conditions that are relatively easier to achieve in today’s education.

Eventually, collaboration in STEAM and for STEAM can be seen as part of a wider ethical stance, which challenges traditional hierarchies, values all disciplines equally, and ensures equitable access to resources, facilities, and opportunities. However, among all Final questionnaire items relating to school climate and culture, the one about all disciplines valued equally, ensuring equitable access to opportunities and resources was assessed as the most difficult to achieve condition, with only 1 in 10 respondents considering it easy to achieve.

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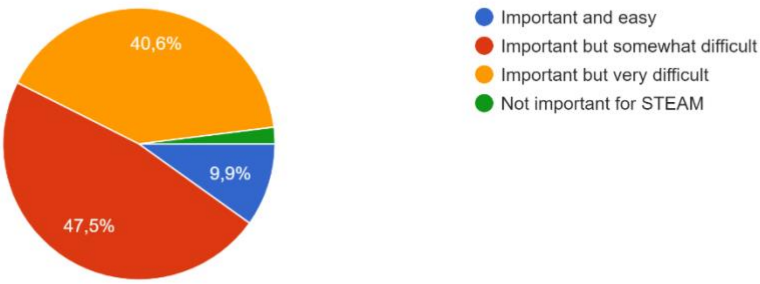
All disciplines valued equally, ensuring equitable access to opportunities and resources
101 απαντήσεις



School organisation and structure

To address the challenges, opportunities, conditions and requirements for the integration of STEAM practices into the educational landscape, a shift in school organization and leadership is required which will allow school structures to foster a culture of innovation and collaboration, providing resources, and offering targeted support and professional development opportunities (Parlar, 2017; Gil et al., 2018).

In the workshop and questionnaire data we analysed, strong support to giving space and time for STEAM within the school was evident. For example, respondents to the Exploratory questionnaire very strongly disagreed with the statement that "*STEAM education can only take place outside school, because there is no space and time for it in the reality of the school*" (Mean=1,65; Median=1; Likert scale: 1=Absolutely disagree - 5=Absolutely agree).

We also observed wide agreement that the whole school structure needs to be revisited towards a notion of a flexible educational ecosystem that can afford breaking disciplinary silos and building bridges between segregated areas of the curriculum, as traditional compartmentalized structures hinder multidisciplinary, interdisciplinary or transdisciplinary collaboration, which is a core tenet of STEAM. However, current conditions in schools seem to be far from the degree of flexibility required to support teachers' collaboration on joint teaching practices and project, as responses to the relevant Final questionnaire item clearly demonstrate, with only about 19% of participants assessing this as an easy to achieve condition.

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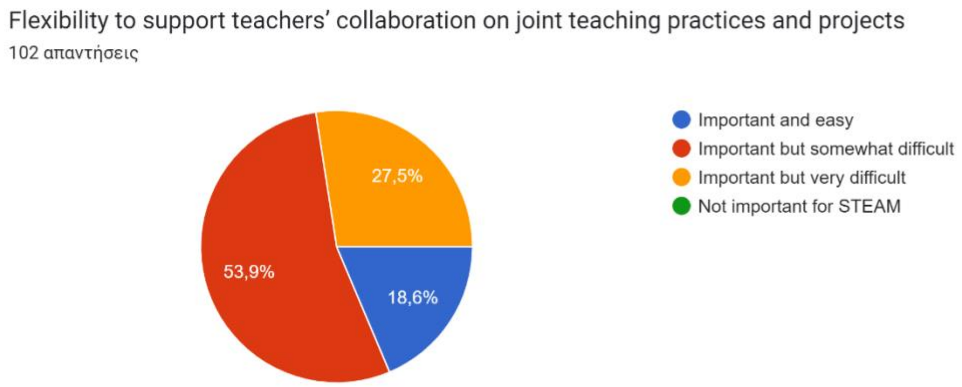

Further, in workshop discussions it was considered paramount that school leaders and systems should effectively deal with the inherent time constraints. Participants pointed out that school leaders should champion flexibility in that respect, e.g. by restructuring schedules and classrooms to enable cross-disciplinary projects and team teaching. It was pointed out that while overburdened schedules leave little room for exploring and integrating new approaches such as STEAM, time management strategies and workload reduction could support innovation adoption and development.

Final questionnaire responses fully confirmed that time related issues are one of the most important conditions to address in any effort to integrate STEAM in education. Availability of time for STEAM within the core school schedule was deemed as very difficult to achieve by about 58% of the respondents, and the possibility to use core school schedule time flexibly was considered as easy to achieve by only about 9%. The possibility to use time for STEAM outside the core school schedule also emerges from the Final questionnaire data as a very significant challenge. It is important to note that the possibility to use time flexibly within the core school schedule, and the availability of time within the core school schedule are the third and fourth most difficult to achieve among all of the conditions for STEAM integration in education that we studied.

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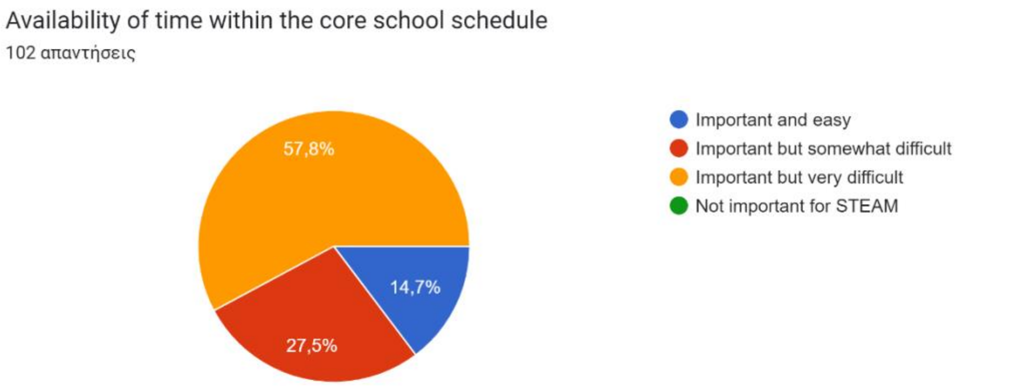

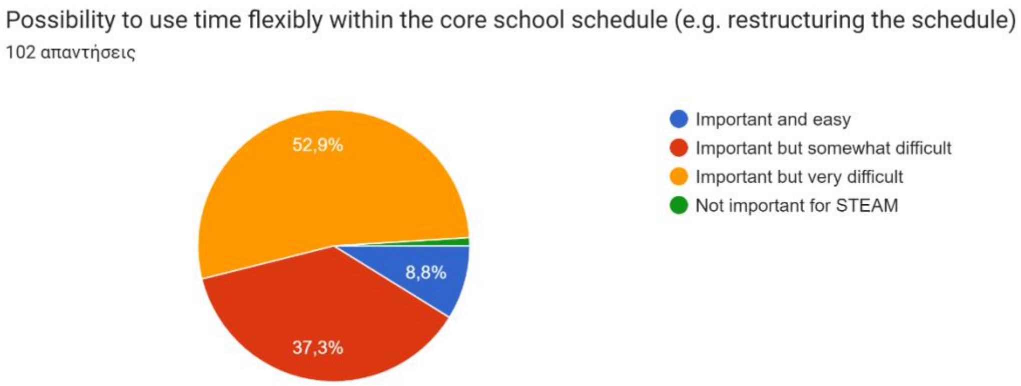

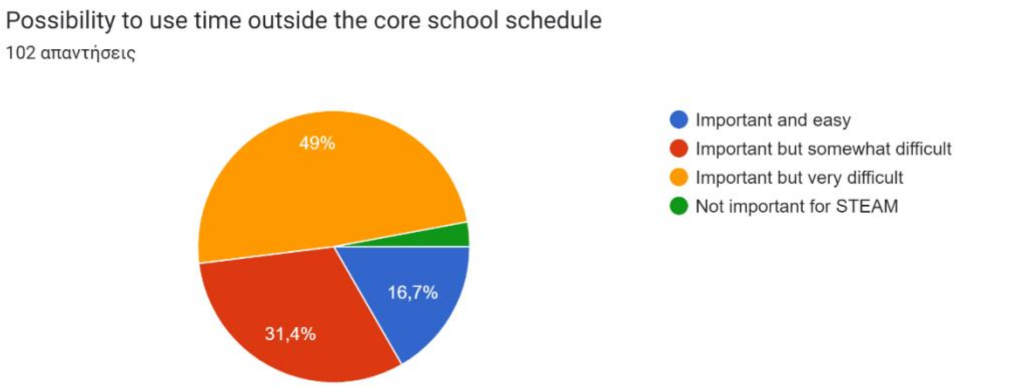

Availability and fluidity of resources is a further urgent step for school leadership to take. According to the responses to the Barriers questionnaire, financial resources and infrastructure are the second most important barrier to the integration of STEAM in education (Mean=4,03; Median=4; Likert scale: 1=Least important barrier - 5=Most important barrier).

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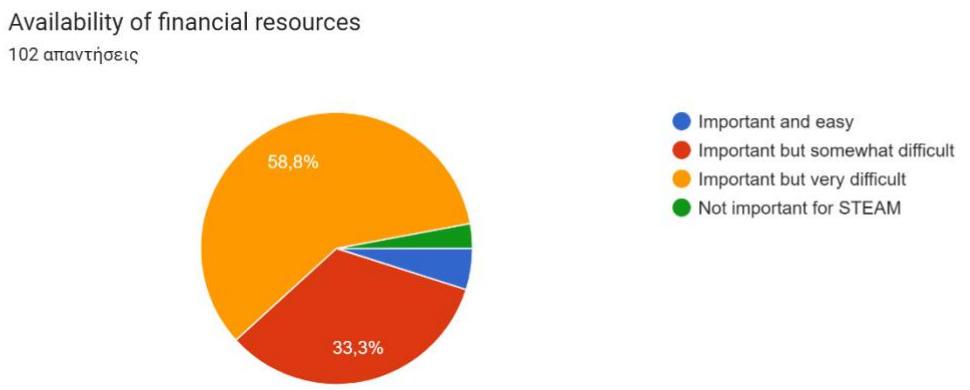
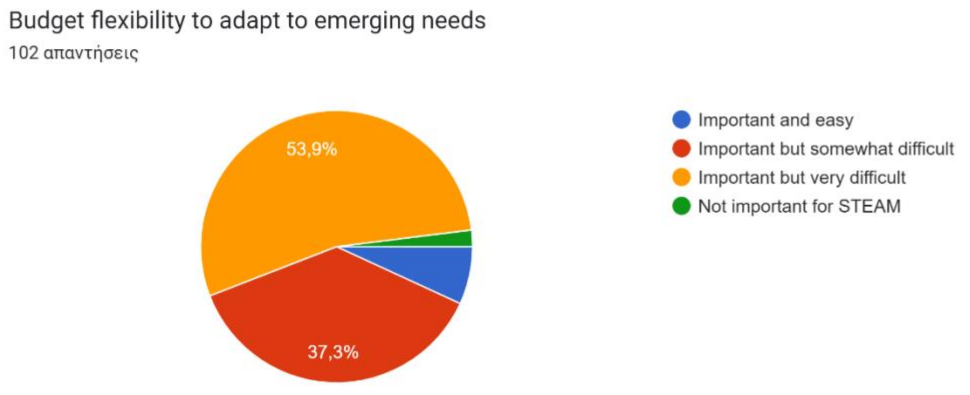
Indeed, the availability of financial resources for STEAM clearly emerges from the Final questionnaire responses as the most difficult among all of the conditions for STEAM integration in education that we studied. Almost 59% of the respondents characterised it as very difficult to achieve, and an additional one third as somewhat difficult to achieve.



In addition to the availability of financial resources, workshop participants also stressed the importance of flexible budgeting that would support the development of STEAM initiatives enabling access to materials, technology, and external support as required by the various STEAM activities. However, according to Final questionnaire responses, budget flexibility to adapt to emerging needs is the second most difficult among all of the studied conditions for STEAM integration in education. Almost 54% of the respondents characterised it as a very difficult to achieve condition, and a further 37% as somewhat difficult to achieve.



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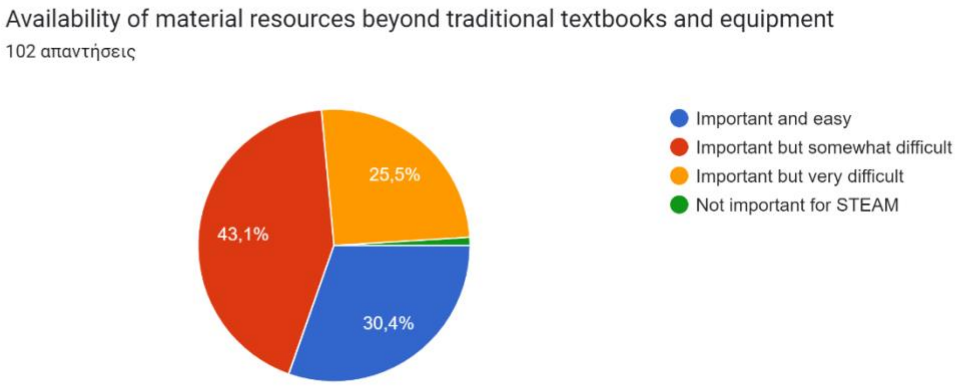
Furthermore, in workshop discussions it was pointed out that, by nature, STEAM practices may require diverse resources beyond traditional textbooks and lab equipment. In particular, pedagogically driven exploitation of technology and its seamless integration as a facilitator is considered essential, e.g. by providing access to appropriate tools for collaborative design, gamification elements for playful learning, and digital platforms that enable co-creation and knowledge sharing. It is encouraging that about 30% of the Final questionnaire respondents indicated that the availability of material resources beyond traditional textbooks and equipment is an easy to achieve condition.



The use of physical space within and outside school is another important aspect relating to resources and infrastructure as conditions for the integration of STEAM in education. Although these too were considered by participants as areas of significant challenge, final questionnaire respondents were generally more optimistic about these conditions than about the availability of time and financial resources. This becomes evident from the responses linked to the statements about space availability for STEAM activities within the school, the possibility to use the school space flexibly, as well as the possibility to use spaces outside the school.

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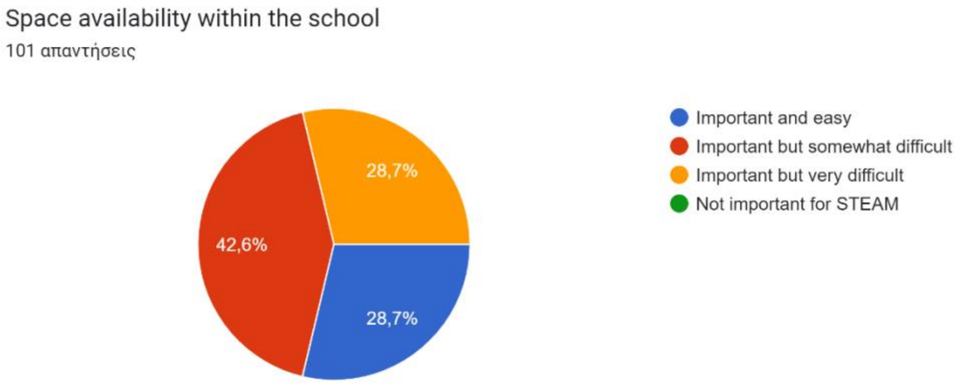

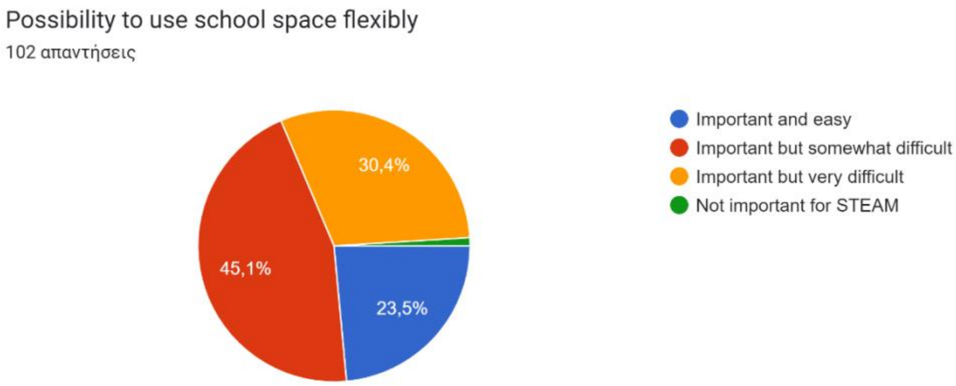

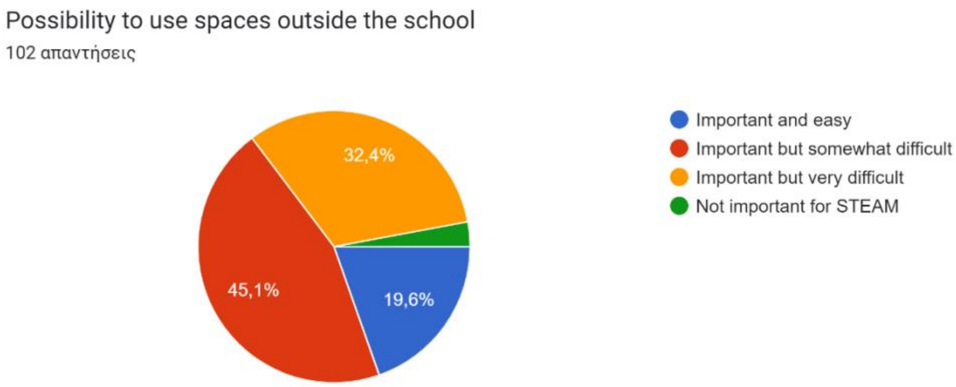

External links and sustained support

As part of the shift from authority to distributed leadership discussed further above, workshop participants noted that to effectively promote STEAM in today's education, this shift should extend beyond classroom and school walls, to embrace community engagement. In particular, participants considered it very important that school leaders

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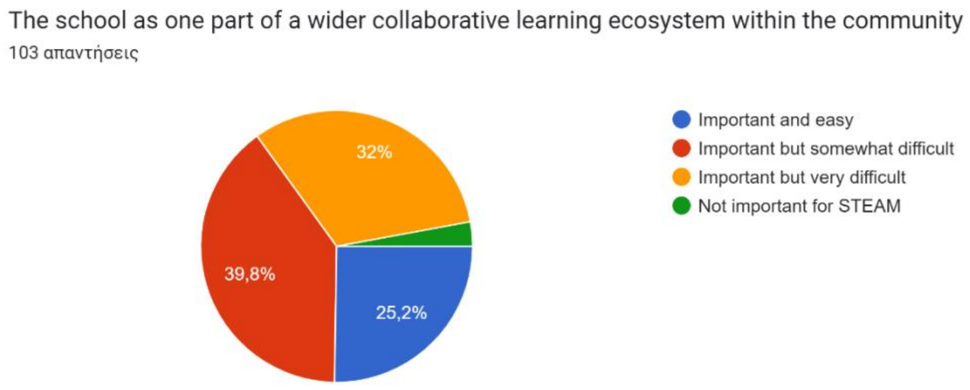
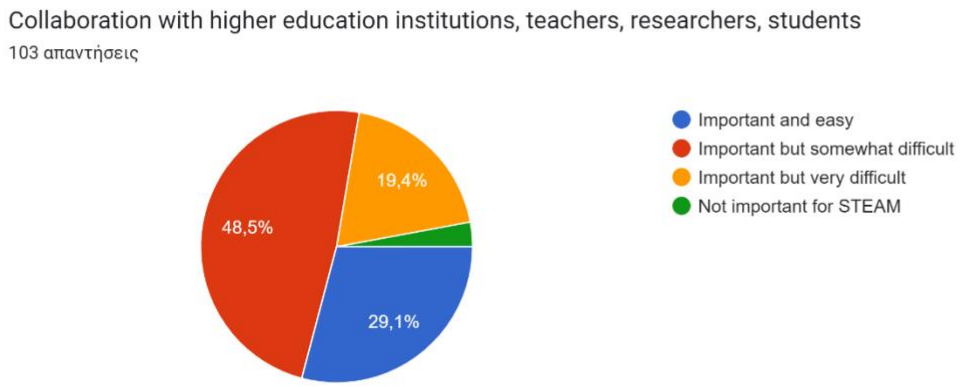
actively engage parents, the local community and other stakeholders. The aim should be to create a collaborative learning ecosystem an integral part of which is the school and which enables and enriches STEAM learning experiences. This notion is discussed in more detail in section 2.3.1 further below, in connection to opportunities for STEAM education through external and cross-sectoral synergies in the realm of open schooling initiatives.

However, it is worth noting at this point that relevant responses to the Final questionnaire indicate an “average” level of perceived difficulty to achieve making the school as one part of a wider collaborative learning ecosystem within the community, with a quarter of the respondents marking this as easy to achieve. Interestingly, respondents also indicate that it is somewhat easier to develop collaboration with informal/non-formal learning spaces and practitioners, compared to the collaboration with higher education institutions, teachers, researchers, and students.





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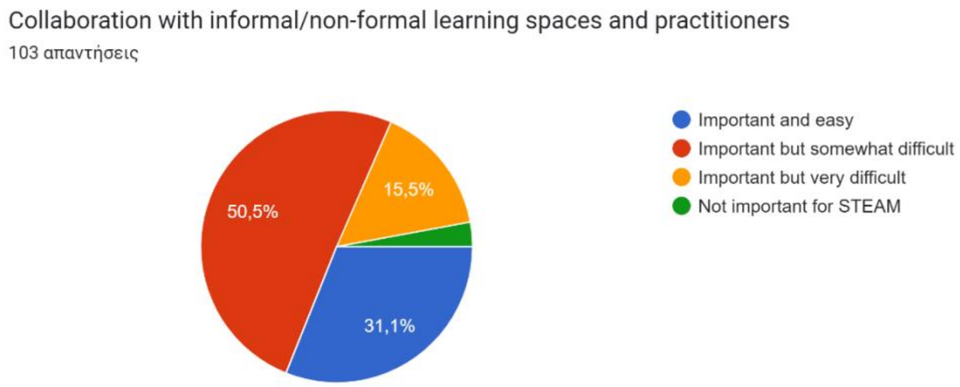
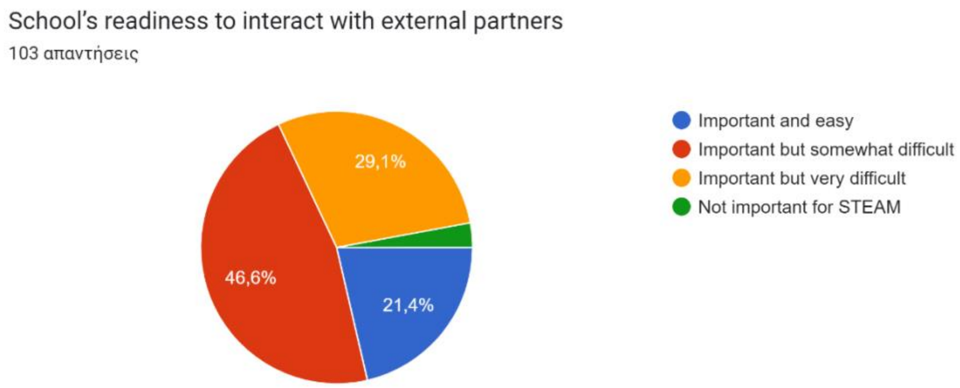
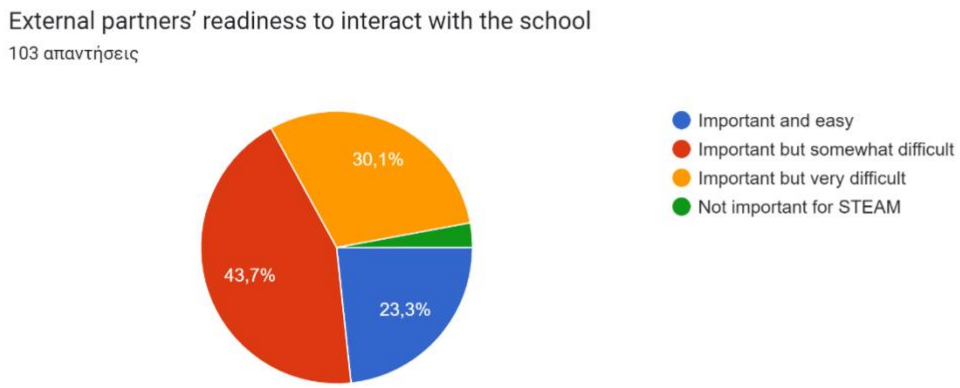


Furthermore, the data gathered through the Final questionnaire demonstrate similar levels of the perceived readiness of the school and of external partners to interact with each other.





Nevertheless, as discussed further above in the subsection on collaborative and equitable culture, when the focus of the question shifts from interaction to <u>*collaboration*</u>,

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it is considered far more difficult to foster collaboration among students, teachers and actors from outside school.

Supporting the sustainability and scalability of STEAM-related innovation should be a further priority area for school leadership, according to workshop discussions. To effectively implement STEAM and generate evident positive impact, long-term commitment and planning are required. Effective advocacy to students, parents, and wider communities is also crucial, with school leadership publicly actively communicating the value and impact of STEAM education on student learning and future readiness. Workshop discussions focused on these as important conditions that can lead to securing community buy-in and sustainable support and funding models for STEAM.

Nevertheless, it is quite encouraging that participants did not consider public awareness and parental support as areas of strong concern. According to the responses to the Barriers questionnaire, lack of public awareness and support and parental concerns and misconceptions are the end of the list of barriers to the integration of STEAM in education (Mean=3,35 and 2,59 respectively; Median=4; Likert scale: 1=Least important barrier - 5=Most important barrier). Similarly, in the Exploratory questionnaire, respondents were ambivalent about the statement "*Parents and the environment outside my school favour the implementation of STEAM activities*" (Mean=3,08; Median=3; Likert scale: 1=Absolutely disagree - 5=Absolutely agree).

Responses from the Final questionnaire help investigate public awareness and parental support for STEAM education in more detail. Respondents clearly tend to consider it quite easy to provide convincing evidence supporting the integration of STEAM in education. Both the recognition of the pedagogical value and benefits of STEAM, and the availability of evidence on the effectiveness and positive impact of STEAM practices are among the conditions that are strongly perceived as easier to achieve.

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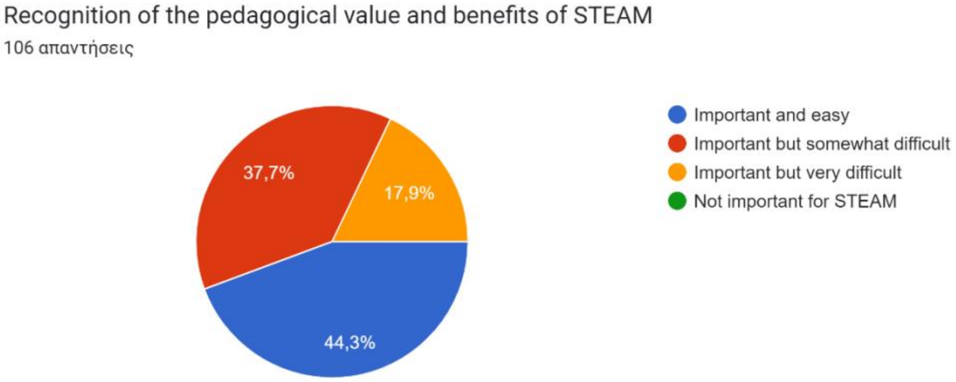
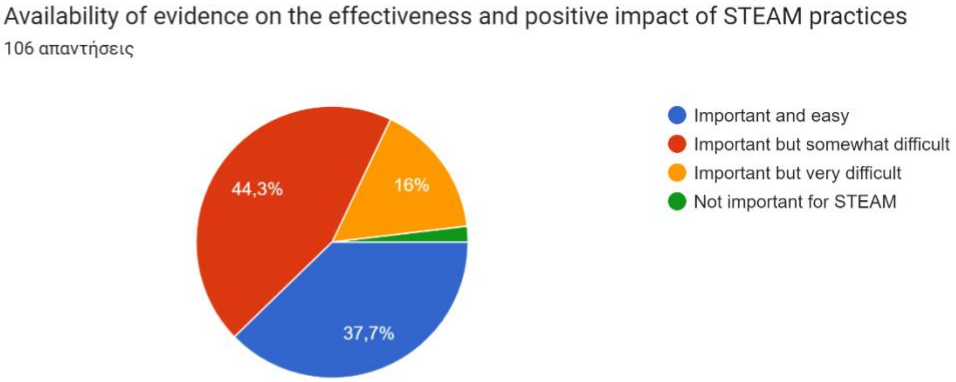
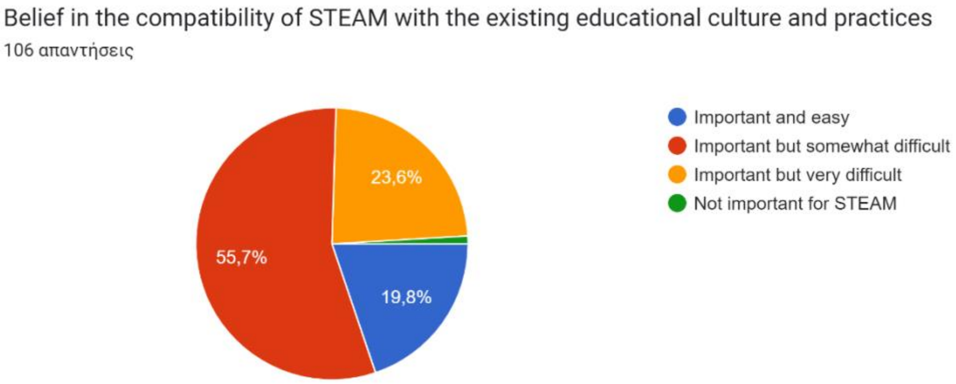




However, this is in stark contrast to respondents' "pessimism" in relation to the conditions of belief in the compatibility of STEAM with the existing educational culture and practices, as well as the compatibility of STEAM with social norms, beliefs and expectations regarding education. Both these conditions are perceived as quite difficult to achieve.



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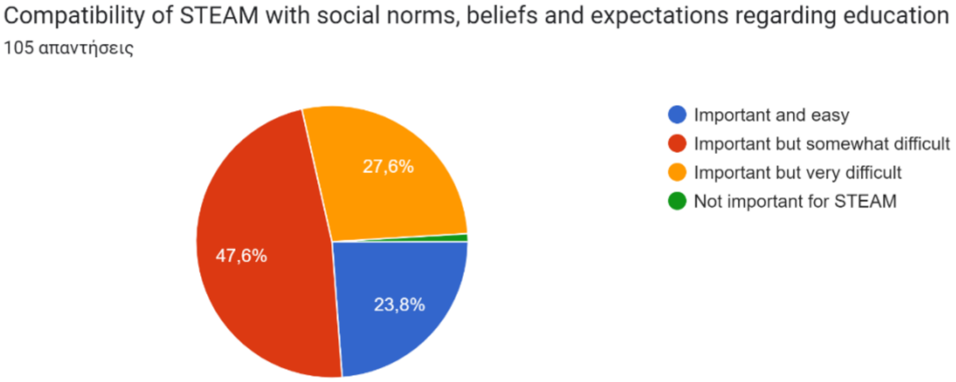
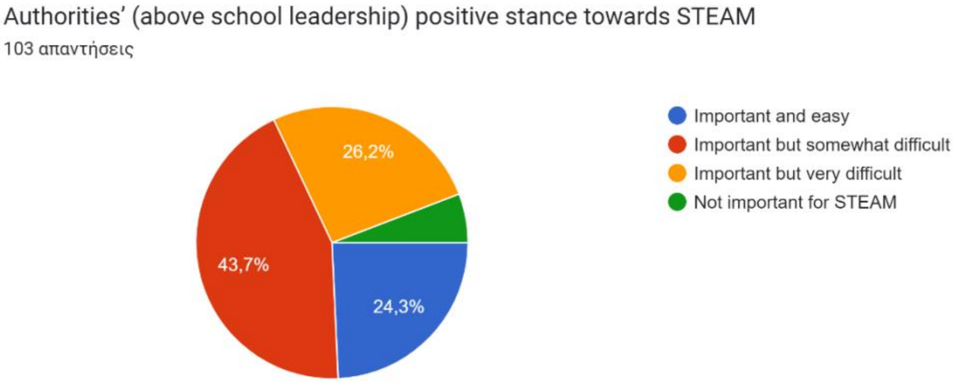


Furthermore, while the positive stance towards STEAM of authorities above school leadership is marked as a condition of 'average difficulty' compared to all conditions studied, parents' positive stance towards STEAM activities and more generally parents' active engagement with school life are characterised by respondents as relatively easier to achieve – and easier than authorities' positive stance. On the other hand, it is also worth noting that the two statements pertaining to parents' engagement and positive stance are among the very few Final questionnaire items that some respondents consider as not important for STEAM – albeit with those respondents representing a very small minority in the sample.



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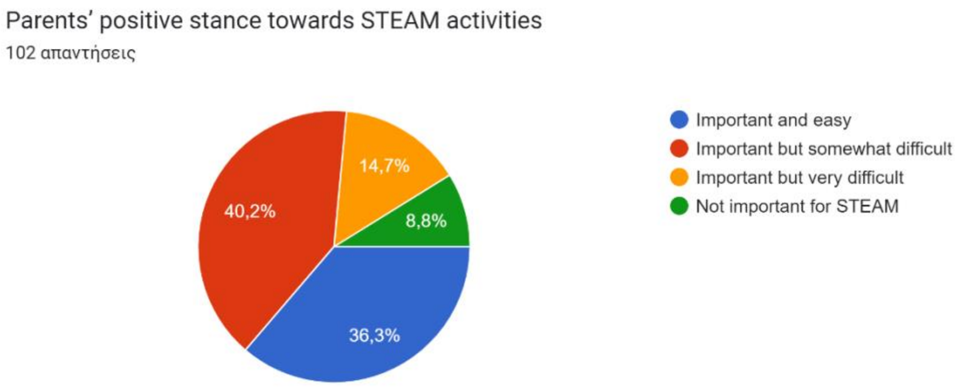

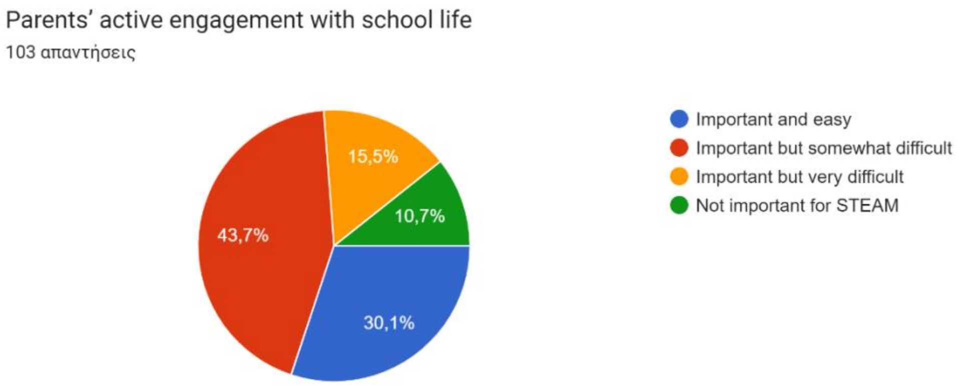

Linked to securing sustainable support for STEAM education is the need to create processes and structures that allow for ongoing evaluation and improvement of STEAM practices. Nevertheless, participants pointed out that evaluating the impact of STEAM is a challenge that requires a nuanced approach beyond standardized testing. Given the important need for evidence-based decision making, leaders should recognise the value of generating impact evidence through the collection and analysis of both qualitative as well as quantitative data integrated with continuous formative assessment of student learning, aiming to shed more light on aspects such as student engagement, collaboration, and the development of soft skills and wider competences fostered through STEAM practices.

However, as discussed in the section on the curriculum (section 2.2.1), learning assessment practices that go beyond traditional testing to cover aspects such as student engagement, collaboration and wider competence development, as well as the use of learning assessment practices to help in the ongoing evaluation and improvement of educational practices, emerge from Final questionnaire responses as

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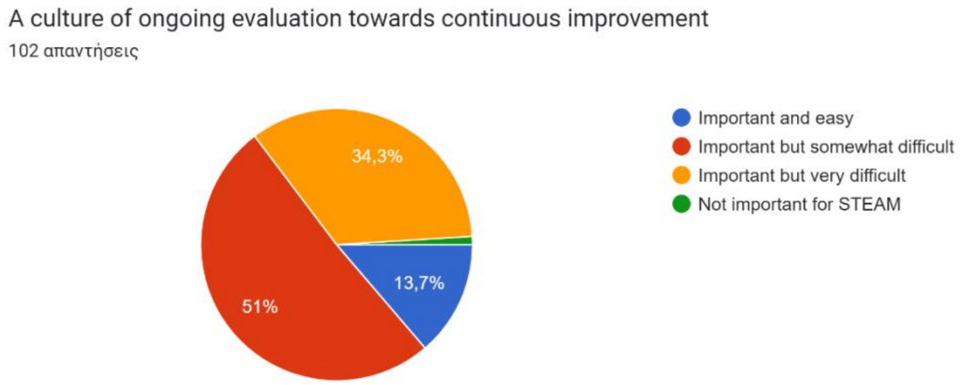
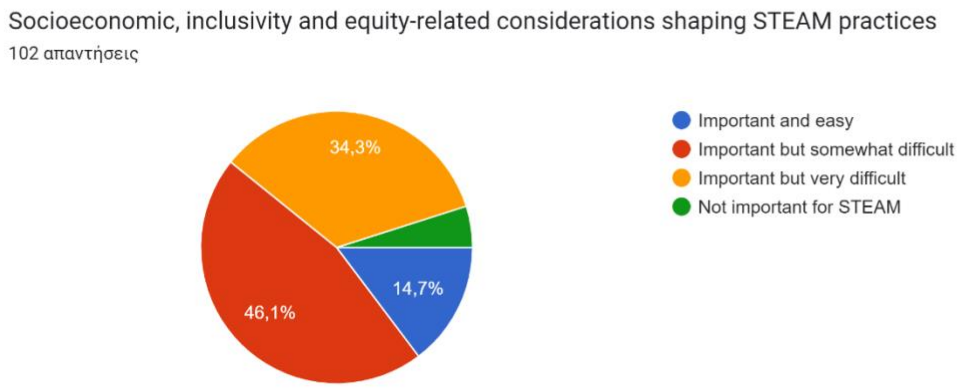
conditions that are very difficult to achieve. What is more, a culture of ongoing evaluation towards continuous improvement was also considered by Final questionnaire respondents as a particularly difficult to achieve condition.



Finally, it should be noted that among the Final questionnaire items pertaining to the external environment of the school, shaping STEAM practices on the basis of socioeconomic, inclusivity and equity-related considerations emerges as one of the quite challenging conditions, with only about 15% of the respondents considering it as easy to achieve.



2.2.4 Teacher support and professional development

Fostering a culture of teacher support and professional development is paramount for continuous school improvement (Kilag and Sasan, 2023). Bubnys and Kauneckienė (2017) stress the importance of aligning personal and institutional development needs to support teachers effectively and cultivate a culture of continuous learning within the organization. Furthermore, studies by Watts & Richardson (2020) and Monroe-

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Baillargeon and Shema (2010) underscore the role of leadership in fostering professional development and creating a culture of collaboration and continuous improvement. By supporting teachers' intellectual passions, promoting collaborative learning, and establishing a culture of safety and vulnerability, school leaders can enhance the professional capital of teachers and contribute to school improvement efforts. Moreover, research by Affandi et al. (2019) and Furqon et al. (2018) emphasize the importance of creating supportive conditions and professional learning communities within schools to facilitate teacher collaboration and continuous learning. These collaborative environments enable deep team learning, critical reflection, and ultimately contribute to ongoing professional development and improved teaching practices.

Furthermore, to provide effective professional development and support, it is important to recognize the complexity of teachers' role not as isolated agents, but as professionals operating within a dynamic interplay of individual, school-level, and external factors. Next to building teacher support and professional development around the concept of teacher agency (Priestley et al., 2015; Calvert, 2016) as discussed further above, it is also useful to approach these efforts through the lens of investing in teachers' professional capital as a key to transforming teaching (Hargreaves and Fullan, 2013; Hargreaves and Fullan, 2015). Professional capital is a powerful concept that challenges traditional power structures and envisions a more collaborative, dynamic future for education, foregrounding teachers as valuable resources. This goes beyond teachers' individual skills and knowledge, dynamically combining strong subject matter understanding, effective teaching practices, and the ability to adapt to diverse learners, with collaboration with colleagues, building trust with students and families, and fostering a positive school culture, as well as teachers' capacity to critically reflect, experiment with new ideas, and contribute to school improvement. This collective capital thrives when nurtured through supportive systems and shared ownership, in schools where teachers are empowered to lead, share best practices, and learn from each other, while leadership trusts and invests in educators, fostering autonomy and professional growth, and systems recognize and reward teacher expertise, collaboration and innovation.

On this background from literature, workshop participants discussed and agreed that cultivating a vibrant STEAM environment necessitates ongoing professional development and support for both teachers and leaders, providing opportunities for all school professionals to deepen their understanding of STEAM pedagogy and

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multidisciplinary, interdisciplinary or transdisciplinary collaboration, and successfully implement innovative STEAM practices.

Workshop discussions also emphasised that to support teacher agency and invest in teachers' professional capital in connection to the integration of STEAM in education, schools and school systems can complement and extend traditional pre-service and in-service teacher training schemes by fostering the development of collaborative learning communities within schools or professional networks. This can foster knowledge and best practice sharing among teachers across disciplines, provide social support with troubleshooting challenges, and encourage the co-creation of STEAM teaching resources as well as experimentation and risk-taking with new approaches. Effective ongoing mentorship and support structures can also help address teachers' negative experiences and rebuild confidence, including by connecting them with experienced STEAM educators and providing access to expert resources.

More generally, it was widely agreed among participants that such efforts need to be part of a wider high-quality, sustained professional development and support provision that will address specific needs and contexts, empowering teachers to effectively develop and implement STEAM approaches through the development of certain skills and a 'STEAM mentality'.

Participants particularly pointed out that emphasis should be put on teacher transformation and the evolution of the traditional role of the teacher as instructor and sole knowledge holder. It was argued that STEAM demands facilitators, guides, and advisors who empower student-led collaborative, exploratory and inquiry-based learning, and provide constructive feedback. For this, teachers also need to be equipped with formative and authentic assessment strategies that evaluate student progress, creativity, and problem-solving skills within the multidisciplinary, interdisciplinary or transdisciplinary context, as well as with the ability to integrate multiple learning modalities into their STEAM activities allowing each student to engage and contribute meaningfully using their unique strengths.

In addition, workshop discussions confirmed that pivotal for effective teacher support and professional development towards the integration of STEAM is education is a focus on multidisciplinarity, interdisciplinarity or transdisciplinarity, moving away from siloed disciplinary knowledge limits towards equipping educators with a foundational understanding of STEAM disciplines and their interconnectedness, as well as exposing

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teachers to relevant real-life practices and applications that will enrich their understanding of the STEAM approach. According to participants, it is particularly important to combine this with supporting and training teachers to move beyond textbooks and conventional teaching scenarios, towards designing open-ended, real-world problem-solving opportunities that will guide students through collaborative and creative problem-solving.

Workshop discussions also highlighted the fact that, as traditional pedagogical approaches focused on theory alone fall short in STEAM, an emphasis on arts-oriented and hands-on experiences as well as on embracing the teacher as a designer and creator is essential. To promote the true integration of artistic practices as core components of STEAM, training opportunities should include exposing teachers to diverse art forms and providing them with the skills to guide students in using art for expression, communication, and creative problem-solving. As participants noted, professional development and support programmes should further encourage teachers to engage in design, prototyping, and making activities such as those they want to develop with their students. As part of this, effective training and support should also equip educators with the pedagogical skills to confidently integrate various technologies into their teaching practices, as STEAM can thrive on technology integration and teachers' technological fluency.

However, the provision of appropriate teacher support and professional development for the effective integration of STEAM in education emerged from participants' responses as a significant challenge. According to the responses to the Barriers questionnaire, time and resources for professional development is at the top of the list of most important barriers to the integration of STEAM in education (Mean=4,30; Median= 5; Likert scale: 1=Least important barrier, 5=Most important barrier). In addition, in the Exploratory questionnaire, respondents tended to disagree with the statement "*I receive adequate training on teaching with the STEAM methodology*" (Mean=2,62; Median=3; Likert scale: 1=Absolutely disagree - 5=Absolutely agree), while they were ambivalent about the statement "*I am sufficiently informed about training opportunities on teaching with the STEAM methodology*" (Mean=3,00; Median=3; Likert scale: 1=Absolutely disagree - 5=Absolutely agree).

Relevant Final questionnaire responses corroborate these findings. The conditions of appropriate pre-service teacher training, and of the availability of relevant in-service teacher professional development opportunities are reported by respondents as

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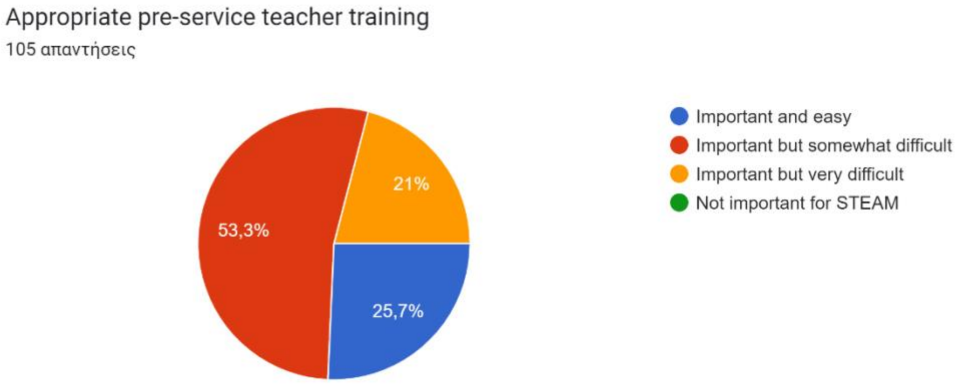
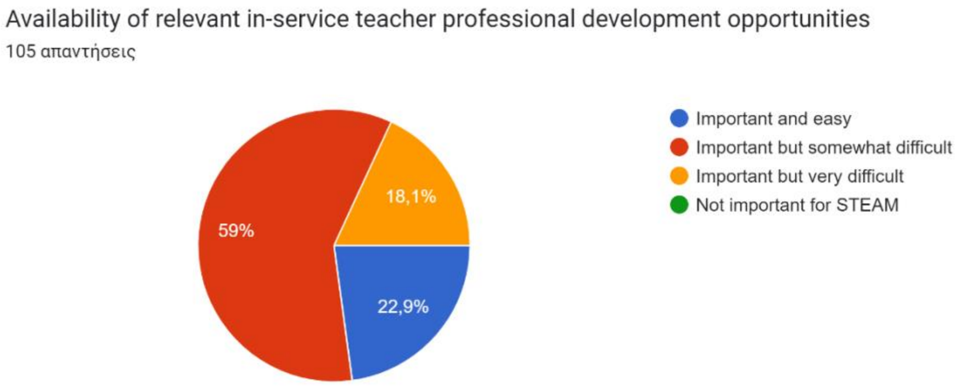
challenging, albeit at an “average” level of difficulty to achieve them compared to the other questionnaire items.





Nevertheless, the condition of in-service professional development tailored to teacher’s individual needs appears in the responses as significantly more difficult to achieve, with only 13% of the respondents characterising it as easy to achieve. Similarly, the availability of teacher support structures and schemes, such as mentorship, peer coaching, collaborative learning communities etc., is also reported to be a quite difficult condition, with only about 18% of the respondents characterising it as easy to achieve.

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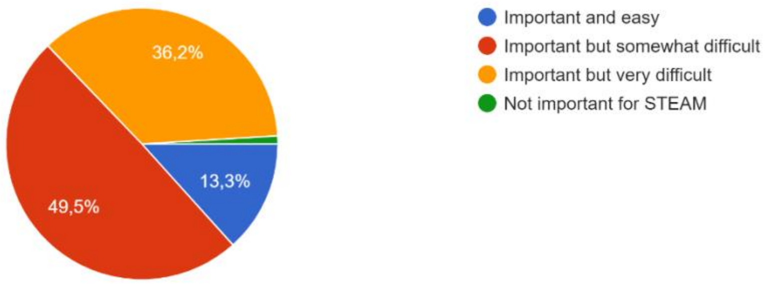
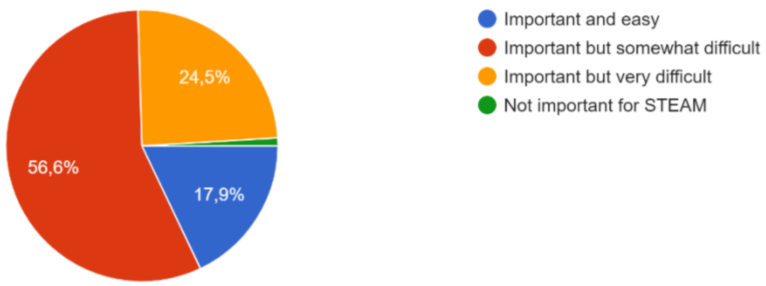
In-service professional development tailored to teacher's individual needs
105 απαντήσεις



Availability of teacher support structures and schemes, e.g. mentorship, peer coaching, collaborative learning communities etc.
106 απαντήσεις



2.3 Opportunities for STEAM

Our study of the current educational landscape has revealed some interesting opportunities arising for the integration of STEAM in education through possible links and synergies with current tendencies and topical issues in education and policymaking at the European level. These include aspects such as open schooling approaches to education, efforts towards creating an integrated learning continuum through synergies between formal, informal and non-formal education, practices such as making and digital fabrication linked to design thinking, playful learning, as well as links to the big challenges of our times and the relevant European policy areas such as the Green Deal, Digitisation, and Health. In the following sections we present information and the main arguments on these possible spaces of opportunity for STEAM education that emerged in the workshop discussions.

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2.3.1 Opportunities for external and cross-sectoral synergies: STEAM and open schooling

The review of the literature and workshop discussions clearly showed that recent and current research projects and relevant initiatives at the European level relating to the engagement of schools with their surrounding communities present significant interest from a STEAM practice perspective, and possible opportunities for synergistic efforts that can serve the aim of integrating STEAM practices in education. This is particularly relevant from the viewpoint of developing STEAM initiatives in collaboration with actors from outside school, not only to provide STEAM practices with external support and resources, but importantly also in order to link STEAM practices with addressing the needs of local communities and society at large. Such synergies are also particularly pertinent to the specific interest of the Road-STEAMer project in STEAM practices that promote synergies between secondary and tertiary education, as well as between formal and informal/non-formal learning experiences.

A open schooling, whole-school approach

In this context, a particularly interesting case are European projects centered on the concept of open schooling in connection to science education, whereby open schools are envisioned as open to society, becoming agents of community well-being in cooperation with other stakeholders, by creating new partnerships in their local communities[1].

Open schooling is also an integral part of the overall conceptualization of the Road-STEAMer project. Road-STEAMer focuses on harnessing STEAM approaches to effectively integrate open science and open schooling practices with science education, which is seen as pivotal for addressing pressing scientific and societal needs in Europe. Open science emphasizes collaborative work and the widespread sharing of knowledge and tools throughout the research process. It involves engaging various stakeholders, including citizens and civil society, in co-creating research agendas and content. On the other hand, open schooling aims to connect schools with society, making them hubs for community well-being through partnerships with local stakeholders. Road-STEAMer proposes to use open science and open schooling to leverage the external world as a unifying force bridging the gaps between different educational levels, research endeavours, and societal actors, and thus integrate

[1] https://cordis.europa.eu/programme/id/H2020_SwafS-01-2018-2019-2020

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students' everyday realities into their educational experiences. Through STEAM education students can gain a holistic understanding of how these diverse aspects of society are interconnected, and are equipped with the skills and knowledge necessary to address complex real-world challenges, ideally within a seamless continuum of learning that integrates secondary and tertiary education while fostering synergies between education, informal/non-formal learning spaces and other societal sectors.

In particular, workshop discussions pointed to Open Schools for Open Societies (OSOS) as a seminal open schooling project[2]. OSOS aimed to transform schools into open, innovative, and democratic ecosystems serving as hubs of science learning and knowledge transfer. Through student-led projects addressing local or global challenges with a focus on social responsibility, OSOS engaged a network of more than 1000 schools across Europe and beyond. The project provided community-building tools, content co-creation platforms, and best practices for student-led science projects tailored to local needs.

Promoting open schooling, OSOS envisioned schools as incubators of exploration and accelerators of innovation. School leaders were encouraged to foster learning experiences equipped to support all learners. Teachers were seen as learning collaborators, continuously acquiring new skills alongside students. OSOS aimed to facilitate this transformation process, empowering schools to become innovative ecosystems where leaders, teachers, students, and the local community shared responsibility, authority, and benefits, enhancing their science capital and fostering responsible citizenship. OSOS aimed to support schools to develop an open schooling culture, providing guidance on staff development, time management redesign, and fostering partnerships with relevant stakeholders. Implementation processes ranged from small-scale prototypes to establishing "open schools within schools" or designing new schools. Project activities in participating schools focused on science themes linked to grand societal challenges and Responsible Research and Innovation, addressing regional and local issues of interest.

Workshop participants particularly focused on the significant opportunities that an approach such as that of OSOS presents for the integration of STEAM in education. Discussions particularly emphasized that such an approach creates a conducive environment for student-led STEAM projects that tackle local or global challenges with a focus on social responsibility. It fosters hands-on, multidisciplinary, interdisciplinary

[2] https://cordis.europa.eu/project/id/741572

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or transdisciplinary learning experiences, whereby students are empowered to explore real-world problems, collaborate across disciplines, and apply creative solutions. Additionally, workshop discussions focused on the framework that approaches such as that of OSOS provide for school leaders and teachers to promote collaboration, continuous learning, and engagement within the school as well as in collaboration with the world surrounding it.

The living lab concept and methodology

Another open schooling project that our study focused on, was Schools as Living Labs (SALL)[3], which proposed a flexible living lab methodology as a way to develop student-centred open schooling activities. In SALL practices, students co-create solutions to real problems from their own real-life experiences through synergies with societal actors from surrounding communities, in the context of cross-curricular, experiential, project-based learning. The Schools as Living Labs methodology was co-created through systematic collaboration with the community of stakeholders, building on existing knowledge and best practices. It was applied in real-life educational settings in more than 400 schools in 10 countries, and the resulting activities and their impact were studied closely. The experiences and evidence gained prepared the ground for sustainable living-lab-based open schooling activities in Europe's schools, through strong community building and policy-oriented interventions.

Workshop participants were introduced into the concept of practices of living labs and discussed their application in educational settings from the viewpoint of STEAM practices. Outside education, in the world of innovation, living labs represent user-centered, open innovation ecosystems that unite diverse stakeholders, including researchers, industry partners, policymakers, and end-users, to co-create, test, and validate innovative solutions in real-world settings. In today's rapidly evolving world, traditional innovation methods, often confined to closed laboratory settings, are inadequate to address complex challenges. Living labs offer a collaborative and user-centric alternative, ensuring solutions are tailored to user needs and preferences. They facilitate rapid prototyping and testing in real-world environments, enabling early identification and correction of flaws, promoting collaboration, and fostering knowledge sharing among stakeholders. By fostering open innovation ecosystems, living labs accelerate innovation, driving economic growth.

[3] https://cordis.europa.eu/project/id/871794

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The SALL project showcased how living labs can greatly enhance education by turning traditional teaching into practical, real-world learning experiences. By immersing students in authentic contexts, living labs deepen understanding, foster essential skills, and ignite a passion for learning. Through hands-on activities and problem-solving, students engage directly with concepts, enhancing comprehension and retention. Collaboration in living labs allows students to design, implement, and evaluate innovative solutions, fostering teamwork, communication, and problem-solving skills vital for the modern workforce. Encouraging creativity and innovation, living labs empower students to tackle challenges creatively and see themselves as agents of change. By bridging the classroom with the real world, living labs make learning more meaningful, showing students how their skills can impact society.

Workshop discussions highlighted opportunities that the living lab approach can offer for integrating STEAM into education. Participants put emphasis on how living lab-based STEAM practices can provide immersive, real-world learning experiences integrating problem-solving, hands-on activities and collaboration, with students engaging directly with scientific, technological, engineering, mathematical, as well as artistic and creative concepts and practices. The discussions also highlighted that STEAM practices based on the living lab approach, with their strong emphasis on stakeholder engagement and external synergies, can effectively bridge the gaps between the classroom and society, between schools and tertiary education, as well as between formal and informal/non-formal learning spaces and experiences, thus making STEAM learning more impactful and meaningful.

The learning ecology concept

In connection to open schooling, our study further looked into the concept of learning ecologies, on which some relevant projects are founded. We focused on the projects STEAM Learning Ecologies (SLEs) and Surrounded by Science (SbS), which we discussed with workshop participants from the perspective of their usefulness in the efforts to integrate STEAM in education.

Building on OSOS and SALL, the STEAM Learning Ecologies (SLEs) project is currently developing engaging open schooling-enabled science learning paths for all in learning continuums of formal and informal learning environments and enterprises, founded on the concept of local partnerships in the form of interconnected knowledge ecosystems: within them, all relevant actors (formal, non-formal and informal education

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providers, enterprises, the civil society) come together and take initiative and central roles to foster improved science education for learners of all ages.

Closely linked to the learning ecology concept is also the Surrounded by Science (SbS) project. SbS develops and applies a systematic assessment methodology to analyze the impact of out-of-school science-related activities on a person's science proficiency. Through a series of field studies and the use of innovative research instruments, the project contributes to a better understanding of how the outcomes of such activities may relate to, and complement, the outcomes of formal science education. In this way, science organizations and science educators are helped to design more effective, targeted, and meaningful learning activities, and foundations are laid for the effective integration and accreditation of informal and formal science education.

In workshop discussions the learning ecology concept was perceived as a powerful and pertinent tool for the promotions and integration of STEAM practices in education. The learning ecology perspective emphasizes the interconnected system of people, places, and experiences that shape learning and development, akin to a natural ecosystem where diverse elements collaborate to foster growth. Examples of learning ecologies vary widely, including interactive classrooms, community centers with diverse learning resources, and families that prioritize learning opportunities. Key components of a learning ecology include individuals (teachers, mentors, peers, family), environments (classrooms, homes, libraries), and experiences (formal instruction, challenges, successes). Learning ecologies evolve through interactions, uniquely shaping each individual's learning path. A healthy learning ecology facilitates deeper learning, critical thinking, collaboration, and real-world readiness. Access to diverse resources and support fosters engagement and motivation, while exposure to different perspectives cultivates problem-solving, teamwork, and communication skills. Learning ecologies also prepare learners for complexity and change, nurturing adaptability and resilience. Building a healthy learning ecology involves fostering supportive relationships, exploring new opportunities, embracing challenges, and reflecting on learning experiences to apply them in life.

Workshop participants agreed that the learning ecology concept offers valuable opportunities for integrating STEAM into education, by underscoring the importance of an interconnected system that supports diverse STEAM experiences embracing ubiquitous, socially constructed, and personalized learning. Participants contemplated how in a STEAM-focused learning ecology, students, teachers, mentors, researchers, artists, creative professionals, families can collaborate within dynamic environments,

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including classrooms, labs, museums, and online platforms. These environments can offer diverse learning content and opportunities for hands-on exploration, experimentation, and problem-solving across STEAM disciplines, integrating formal instruction with informal learning experiences. Workshop participants also focused on how a supportive learning ecosystem can encourage learners to engage with real-world challenges, successes, and failures, promoting adaptability and resilience, and preparing learners for the complexities of the modern world.

Opportunities for STEAM in the realm of open schooling, living labs and learning ecologies

Our study, including both our reading of the literature and the collected participant input, corroborated the idea that STEAM education, as conceptualized in Road-STEAMer, shares several principles and goals with the above presented approaches of open schooling, schools as living labs, and learning continua within learning ecologies. It also becomes evident that synergies with practices and initiatives from those spheres can strengthen STEAM practices and empower STEAM learners and practitioners, including by enabling the building of bridges between schools and tertiary education and between formal and informal/non-formal learning experiences and spaces. It is therefore important that any attempt to integrate STEAM in education should promote STEAM practices as integral parts within this wider transformative framework which recognizes education as an active, interconnected process that extends beyond traditional classrooms, and fosters transdisciplinary, student-centered, hands-on, real-world learning, creativity and collaboration. Additionally, synergies with open schooling, living lab, and learning ecology-based practices and initiatives naturally support strategic partnerships with external stakeholders and community engagement, enhancing STEAM education by providing access to expertise, resources, real-world experiences and creating dynamic and inclusive learning environments that can prepare students for success in a rapidly evolving world.

2.3.2 Opportunities for STEAM connected to real world needs and applications: making, digital fabrication, design thinking, playful learning

Our study also investigated how projects and initiatives in the wider areas of making, digital fabrication, design thinking, and playful learning can be of relevance to efforts for the integration of STEAM in education, given the common focus on real-world

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connections that all these approaches share. Our reading of relevant information and workshop discussions confirmed the opportunities for synergistic efforts that exist. Workshop participants were introduced to the relevant concepts, and the Stories of Tomorrow project was used as an example. Rich discussions evolved which are summarised in the following paragraphs.

The example of Stories of Tomorrow

The "Stories of Tomorrow - Students Visions on the Future of Space Exploration" project[4] aimed to leverage storytelling as a powerful catalyst for integrating art and STEM disciplines, promoting deeper learning among students. By presenting a new vision for teaching, the project outlined strategies for educators to support and facilitate deeper learning experiences. Utilizing advanced digital technologies such as augmented/virtual reality applications and learning analytics, the project sought to enhance students' engagement and exploration of scientific concepts. Central to the project was a digital Storytelling Platform where students were enabled to express their artistic creativity and scientific inquiry simultaneously. Students produced various forms of creative work, from paintings to 3D models, which were integrated into interactive ebooks. Advanced interfaces allowed students to augment and explore their creations in 3D using tablets or computers, enhancing their understanding of scientific principles. The project was piloted in real educational settings involving 60 teachers and 3000 students in the 5th and 6th grades. The collaboration between creative industries, electronic publishing, educational research institutions, schools, and informal learning centers ensured a holistic approach to innovation in education.

Workshop participants discussed aspects of Stories of Tomorrow with the aim to identify good practices that could support the effective integration of STEAM in education, focusing in particular on producing evidence about the positive impact of STEAM and on analysing the conditions for the integration of STEAM into the existing curriculum. On the one hand, workshop discussions related to the research conducted during the Stories of Tomorrow project on the impact on learners, particularly through a Deeper Learning Competence Framework developed to assess learning during the activities, as well as a focus on assessing the development of scientific creativity during digital storytelling (Smyrnaiou et al., 2020). On the other hand, an area that drew participants' interest was the attention paid in Stories of Tomorrow to exploring the conditions and requirements for the integration of the proposed innovation into the

[4] https://cordis.europa.eu/project/id/731872

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existing curriculum (cf. Stories of Tomorrow deliverable D1.6 “Innovative Curricula for 21st Century Learners: From Small to Big Ideas of Science”). The project analyzed curricula in participating countries to identify obstacles and opportunities for the proposed approach, focusing on local alignment and curricular reforms as well as the need for innovative teacher professional development. Experiences from the Stories of Tomorrow project especially underline that teachers play a crucial role in implementing STEAM curricula, requiring support, guidance and opportunities for peer conversations and collaborative work.

Links between STEAM and making, digital fabrication, design thinking, and playful learning

Workshop participants used the example of the Stories of Tomorrow project to develop a discussion on the links between STEAM education and concepts and practices such as making, digital fabrication, design thinking, and playful learning. In summary, the following points emerged as important.

STEAM education intertwines with design thinking and playful learning, forming a nexus of pedagogical approaches that converge on fostering innovative problem-solving skills and deep engagement among students. Design thinking, with its emphasis on human-centered design, iterative processes, and real-world applications, aligns seamlessly with the core tenets of STEAM education. By prioritizing empathy and understanding of user needs, design thinking mirrors STEAM’s focus on creativity, collaboration, and multidisciplinary, interdisciplinary or transdisciplinary thinking. Similarly, playful learning strategies, which emphasize engagement, exploration, and creative problem-solving through joyful and meaningful experiences, resonate with STEAM’s overarching goals. In this context, also practices such as making and digital fabrication and STEAM share a common emphasis on hands-on, experiential learning that promotes creativity, problem-solving, and multidisciplinary, interdisciplinary or transdisciplinary thinking. Workshop participants concluded that by integrating such methodologies and practices into STEAM education, educators can create dynamic, authentic, and enjoyable learning environments that can stimulate students’ curiosity and imagination, and empower them to become adept, adaptable thinkers able to navigate the complexities of the 21st century, with essential skills and mindsets necessary for success in an ever-evolving global landscape.

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STEAM and European policy areas on the big challenges

As part of the workshop discussions on the real-world connections of STEAM practices, we also investigated the opportunities arising for STEAM due to its emphasis on developing educational practices that address topical societal issues and the big challenges of our times. Given that such challenges are being addressed by major policy initiatives at the European level, it may well be possible that STEAM practices can gain additional recognition and support as effective educational approaches within the wider discourses of European policy development in areas such as the Green Deal, Digitisation, and Health. These policy areas were discussed briefly in the workshops, with the aim to inform the participants in an exploration of the possibilities that my arise for the promotion of STEAM education.

As one of the six European Commission priorities for 2019-2024, the European Green Deal represents Europe's ambition to be the first climate-neutral continent by becoming a modern, resource-efficient economy. It is a comprehensive set of policy initiatives aimed at achieving climate neutrality in the EU by 2050. It involves reviewing existing laws and introducing new legislation covering areas like the circular economy, building renovation, biodiversity, farming, and innovation. The Green Deal targets various sectors such as construction, energy, transport, and food, with measures like the Circular Economy Action Plan and the Farm to Fork strategy. Despite challenges such as the need for substantial investments, technological advancements, and international cooperation, the EU aims to lead global efforts in addressing climate change and promoting sustainable development through the European Green Deal.

Another area of intensive policy making at the European level is centered on the goal to make Europe fit for the digital age by empowering people with a new generation of technologies. While digital technology is changing people's lives, Europe's digital strategy aims to make this transformation work for people and businesses, while helping to achieve its target of a climate-neutral Europe by 2050. Thus, the EU Digital Strategy aims to position the EU as a leader in the digital economy while ensuring privacy rights and fair competition. It encompasses several key initiatives, including the Data Strategy, which seeks to create a single European market for data, and legislation like the Data Governance Act, the Digital Services Act, the Digital Markets Act and the Artificial Intelligence Act. The European Commission is determined to make this Europe's "Digital Decade", with Europe strengthening its digital sovereignty and setting standards, rather than following those of others.

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In the area of Health, EU member states manage health services, with the EU complementing national efforts. EU health policy aims to enhance citizens' health, modernize infrastructure, improve health system efficiency, and respond to cross-border health threats. The EU adopts laws covering areas like patients' rights, medicines, and public health. Coordination addresses challenges like antimicrobial resistance and chronic diseases due to free movement. Initiatives include the European Health Data Space, promoting access to health data and interoperability. Regulations govern medicines, medical devices, and preparedness for health emergencies. The EU also focuses on cancer prevention, tobacco control, and vaccination. Legislation ensures the safety of substances like blood and organs. Mental health and eHealth are prioritized, especially during the COVID-19 pandemic, where the EU supports vaccine distribution, medical supply provision, and research.

In this wider policy context, workshop discussions evolved on possible links between STEAM education and the big challenges of our times as represented in the relevant European policy areas. Participants felt that by aligning STEAM practices with key policy areas, education can empower the younger generations to tackle complex challenges and contribute to building a more sustainable, digitally connected, and healthy future.

Regarding the Green Deal, STEAM practices could focus on real-world problems linked, for example, to sustainable technologies and promoting resource efficiency for the circular economy. Thematic areas of STEAM projects could include climate-smart agriculture, waste reduction, and product design for sustainability, design and development of sustainable cities, energy-efficient buildings, sustainable transportation systems, to name a few.

In the realm of digitization, STEAM practices could prioritise dealing with themes such as equipping individuals with digital literacy, cybersecurity knowledge, and skills for digital transformation in various industries. Examples of possible STEAM project themes include the development of initiatives that foster informed decision-making and responsible digital citizenship, or enable individuals to safeguard personal information and contribute to a secure digital environment.

Finally, with regard to health, STEAM practices could support educating school and local communities in preventive healthcare and fostering a healthy lifestyle.

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3. Examples of implementing STEAM in the existing school curriculum

3.1 Introduction

As examples for implementing STEAM practices in an existing school curriculum, a selection of successful case studies that have taken place in Greek schools and in real settings will be described in this part of the report.

All practices introduced here are described regarding their connection with the competences mentioned in the Analytical Programme of Studies (APS) which is issued by the Greek Ministry of Education and the Institute of Educational Policy (IEP). In addition to the APS, the Interdisciplinary Comprehensive Programme of Studies (ICPS) introduces the so called “flexible zone” within the school curriculum.

References of connection between the proposed practices and the curriculum mentioned in the above documents are selected according to the areas these practices focus on, with a particular emphasis on the Arts.

Interdisciplinarity in the “Flexible Zone”

Apart from “research projects” that require out-of-school activities or engagement in "research" purposes (e.g. collecting materials and data), many other types of topics involving students can be chosen. The type of topic chosen determines, naturally, the methodology of its treatment. During the implementation of the 'Flexible Zone' all pupils have to participate in as many projects as possible in groups under the responsibility and guidance of the schoolteachers. Groups may include pupils regardless of the class to which they belong.

Pupils taking part in these interdisciplinary activities are not graded or assessed in the same way as other disciplines on the school timetable. This avoids, as far as possible, any connotation of the 'Flexible Zone' with traditional timetable subjects, the burden and possible standardisation of which this innovation of the IEP aims to relieve pupils of.

Two hours per week per class are allocated to the Flexible Zone. The two hours are integrated into the 35-hour weekly timetable of the secondary school, are specific and

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common to all classes. Due to the complexity of the weekly timetable, three alternative formats are proposed, from which the teachers' assembly of each school will choose the most appropriate for its own needs[5].

Suggested scheme 1: Two-hour non-fixed Flexible Zone

Suggested scheme 2: Two-hour fixed weekly Flexible Zone

Suggested scheme 3: a whole week of Flexible Zone

Focus on the Arts

Interdisciplinarity in the Arts can be achieved through School theatre: Drama, Comedy, Pantomime, Stage performance, Role-playing games. In Music education it is by creating musical ensembles[6]. Concerning the Arts and their connection with creativity in Arts, digital fabrication, playful learning in particular, a selection of competences as described in the APS / ICPS and met by all practices, is hereby presented as follows:

Music

Regarding music, the STEAM practices described here are linked to the following within the music curriculum:

Lower Primary

Pupils should be able to

- Produce simple sound patterns with voice, body and musical instruments.

- Perform in synchrony with others, responding to appropriate instructions.

- Perform rhythmic and melodic patterns from memory and from symbols.

- Develop the ability to control sounds on a variety of musical instruments.

- Share musical creation with different types of audiences.

- Design simple ways of storing and communicating their musical ideas (symbolism).

[5] Greek Ministry of Education, APS/ICPS, page 623
[6] Indicative subject areas for lower secondary education. Greek Ministry of Education, APS/ICPS, page 622

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- Investigate, select and combine sounds produced by the voice, body and musical instruments to produce simple compositions.

- Store their musical ideas and communicate them using appropriate media.

- Explore, select and control sounds to 'compose' a simple piece of music.

- 'Compose' and record their music for later recall, using appropriate signs, symbols, cues or other media.

- Listen to and discuss sounds produced in different ways.

Fundamental interdisciplinary concepts: sound, tradition, culture, communication, cooperation. Extensions in visual arts, language, drama, science, information technology.

Upper Primary

- Sing or play a short solo.

-Investigate, select and combine sounds produced by the voice, the body and musical instruments to produce simple compositions.

-Store their musical ideas and communicate them to others using appropriate media.

-Invent and develop musical ideas that have a simple structure, including repetition and contrast.

-Develop and design a wide range of sounds, and select those that are appropriate for use, exploring a particular technique.

Additional cross-curricular schemes of work: Making improvised musical instruments similar to those of Greek traditional music and using them to perform songs.

Lower Secondary

Students should demonstrate sound control through singing and instrument playing and Performance skills. Students should be able to plan, present and evaluate their performances.

In the field of *Listening and applying knowledge*, they should be able to listen and to discriminate, internalize and recall sounds. They should identify the sources, rules and

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processes of music composition, including the use of information and technology, musical notation and other types of notation used in selected musical genres, styles and traditions.[7]

Lower Secondary Interdisciplinarity

Students should be able to create, evaluate, and revise compositions that sustain and develop musical ideas and show variety, unity, and coherence. Students should be able to compose a set of variations on a given theme. They should also be able to use electronic systems (computers) to create a live performance, using sound processing hardware to change the nature of instrumental and vocal sound (computer science).[8]

Visual Arts

Regarding visual arts and their connection with the studied STEAM practices, the following competences can be highlighted:

Primary

Pupils should use visual arts not only to complement other subjects but also use them interdisciplinarily with other subjects. [9] They should also be able to orally describe a work of art, aptly use simple terms and terms from mathematics (length, symmetry with respect to axis, point, line segment, parallel and perpendicular lines, shapes)[10].

Secondary

Focusing on Mathematics (1st secondary grade) they should use terms such as: length, weight, use of numbers, symmetry on an axis, (2nd secondary grade) point, line segment, parallel and perpendicular lines, shapes[11].

Students should be able to recognize geometrical abstract shapes or simple plant patterns along with drawing triangle, square, parallelogram, pyramid, etc. using geometric instruments[12]. They gain advanced competences in geometric constructions

[7] Greek Ministry of Education, Music APS/ICPS, p.338
[8] Greek Ministry of Education, Music APS/ICPS, p.348
[9] Greek Ministry of Education, Visual Arts APS/ICPS, p.97
[10] Greek Ministry of Education, Visual Arts APS/ICPS, p.102
[11] Greek Ministry of Education, Visual Arts APS/ICPS, p.103
[12] Greek Ministry of Education, Visual Arts APS/ICPS, p.104

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such as polygons, angles, arcs and recognize geometric, floral, traditional motifs and a variety of decorative themes in the proposed visual forms[13].

Exercises to transfer concepts of the natural world into visual artwork (Physics, Chemistry, Biology) are particularly highlighted in visual arts lessons (Topic: Morphological elements). In intersection with Chemistry a special topic is dedicated to Culture and Nutrition but also with chemical technology, water and air pollution. The use of pyramid, cylinder, cone, sphere in relation to mathematics along with measure and measurement, balance, radiation, light and their relation to Physics are also introduced[14].

Theatre/Drama

Regarding Theatre and Drama and their connection with the STEAM practices presented in this section, it should be noted that for both Primary and Secondary Education, theatre and drama lessons aim to encourage students to develop skills and aptitudes to enable them to function harmoniously both as independent individuals and within the group.

In particular, the aim is to:

-Encourage creative expression.

-Help children to get to know themselves, to cooperate and to integrate harmoniously into the group.

-Develop physical and mental abilities.

-Form aesthetic - artistic perception and criteria and produce artistic products (pupils as receivers and creators).

-Become directly acquainted with the artistic and cultural achievements of their own and other cultures.

-Acquire specific knowledge about theatre and other arts and their relationship with culture and society.

-Creative development of expressive skills through language and speech.

[13] Greek Ministry of Education, Visual Arts APS/ICPS, p.114
[14] Greek Ministry of Education, Visual Arts APS/ICPS, p.120 and 121

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-Creative original production of dramatic texts.

-Awareness of the history of ideas and trends in the field of theatre arts which have contributed to the development of European civilisation, and an understanding of the value of intercultural and multicultural education.

-Awareness of the concept of the role.

-Collaborative artistic creation (theatrical performance).

-The direct involvement, participation and intervention of the pupil in the teaching process.

-The productive interconnection of subjects through the applications of drama and the linking of theory with practice[15].

Dance (as part of Physical Education)

Regarding Dance and its connection with the STEAM practices studied, it should be noted that for Secondary education, one of the cognitive objectives in teaching physical education is the acquisition of knowledge related to traditional dance, music and singing at local and national level.[16] For the teaching of dance, it must be ensured that an appropriate atmosphere is created and that appropriate music can be used.[17] The cultivation of rhythm is also included.[18]

Focus on Sciences and Technology

Regarding the formal science education and its interconnection with the artistic concepts and creativity, a selection of competences as described in the APS / ICPS and met by all practices, is hereby presented as follows:

Technology

Concerning the Information and Communication Technologies, pupils should familiarize themselves with the artificial technological environment. - Mathematics in

[15] Greek Ministry of Education, Theatre-Drama APS/ICPS
[16] Greek Ministry of Education, Physical Education APS/ICPS, p. 574-575
[17] Greek Ministry of Education, Physical Education APS/ICPS, p. 583
[18] Greek Ministry of Education, Physical Education APS/ICPS, p. 564

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everyday life, art and culture is a topic under Science and Everyday Life with a title: Applications of Natural, Social Sciences[19].

In lower Primary school pupils should distinguish the differences between the natural world and the man-made world[20], while in early Secondary school students should acknowledge the development of technology as a result of the development of knowledge through research and experimentation[21].

Students are expected to develop a clear understanding of:

-the history and nature of technology (the early stages and evolution of technology, its contribution to modern civilization, the various professions in the field of technology, and the cultivation of practical skills through hands-on construction)

-the link between technology and culture, the way of life and the quality of life in all societies

-the value of technology and its links with other fields of knowledge[22]

In order to critically examine technical alternatives, students use knowledge of mathematics, chemistry, physics, foreign languages, to access sources of information and to write technical reports, etc[23]. They should also be able to understand the selection and use of construction technologies but also to comprehend the design of model constructions and the importance of the constructed artificial environment in everyday life[24].

Physics

Primary school

Pupils should understand how sound is produced, and recognize some basic characteristics and features of sound through interaction.[25]

Secondary school

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[19] Indicative subject areas for lower secondary education. Greek Ministry of Education, APS/ICPS, page 622
[20] Greek Ministry of Education, Technology APS/ICPS, p. 434
[21] Greek Ministry of Education, Technology APS/ICPS, p. 436
[22] Greek Ministry of Education, Technology APS/ICPS, p. 438
[23] Greek Ministry of Education, Technology APS/ICPS, p. 440
[24] Greek Ministry of Education, Technology APS/ICPS, p. 437
[25] Greek Ministry of Education, Physics APS/ICPS, p. 525

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Particularly in Interdisciplinary curriculum in the third grade students examine oscillations and waves along with sound wave propagation, and the objective characteristics of sound. They should also be able to produce simple sounds (demonstration experiment).[26]

As a topic in a Music School (upper secondary): Sound, Music and musical instruments (From Orpheus and Pythagoras to Xenakis and Papathanasiou), students look for differences between a) the European scale and b) the Byzantine mode. They look for the relationship between the emotion produced and the objective characteristics of the sound (frequency, intensity, duration). Extensions of this topic can be in Mathematics, Music, History, Technology, Information Technology, Computer Science, Language.[27]

Chemistry

Students' interaction with the world around them raises questions about materials, whether they are computer components, colours in a work of art, or the DNA of a cell. What is the composition of materials? How, when and why do they change? How do they interact with the environment?[28]

As a laboratory exercise, students prepare pastel colours, and examine their use e.g. watercolour in painting.[29] They also examine the properties of glass as a material in modern technology e.g. fibre optics[30].

In Acid Rain as a topic, students collect information and photographic material about: - how acid rain is created - its effects on the natural environment - its effects on works of art. Among the interdisciplinary concepts of this topic we highlight: Culture and Aesthetics[31].

Mathematics

Primary education

[26] Greek Ministry of Education, Physics APS/ICPS, p. 536
[27] Greek Ministry of Education, Physics APS/ICPS, p. 538
[28] Greek Ministry of Education, Physics APS/ICPS, p. 542
[29] Greek Ministry of Education, Chemistry APS/ICPS, p. 543
[30] Greek Ministry of Education, Chemistry APS/ICPS, p. 554
[31] Greek Ministry of Education, Chemistry APS/ICPS, p. 554

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3rd grade: Proportions are crucial in the understanding of harmony in all kinds of artistic education. Pupils learn about simple proportional units (e.g. 1/2, 1/4, 1/3, 1/8, 1/16, 1/5, 1/10 etc.). They are introduced into fractions with the help of appropriate representations or physical models such as: the clock with its subdivisions, geometric shapes with axes of symmetry, subdivisions of lengths, cutting an apple or a chocolate bar and drawing them can be used for a first introduction to fractions (Aesthetic Education, Environmental Studies)[32].

4th grade: Pupils are able to draw, manipulate and describe geometric shapes and solids using instruments. Particularly in Geometry they should understand intuitively the concept of area and be able to calculate and compare perimeters of plane shapes and also draw the symmetry of a plane figure in relation to an axis of symmetry.[33]

5th grade: Students should be able to add and subtract fractions, to multiply and divide fractions, to solve simple fraction problems and make operations with fractions. They are also introduced in fractions in Music (second, fourth, eighth, as part of Aesthetic Education).[34]

Lower Secondary education

Students begin to study Functions and to express one quantity as a function of another, such as the area of a square as a function of the length of its side. [35] This is crucial in understanding sequences of sound events as a function of time. They continue to operate with fractions (adding and subtracting) and they are introduced to "Fractions in Music and Architecture." as an interdisciplinary lesson blending Mathematics, History and Aesthetics.[36]

Interdisciplinary topics

In Geometry they continue to understand the concepts of perpendicularity, parallelism and symmetry with respect to centre and axis and use them in the analysis of mathematical situations (e.g. characteristic properties of triangle, parallelogram, etc.). Interconnections with Culture, Arts, Similarities-Differences[37] along with "The role of

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[32] Greek Ministry of Education, Mathematics APS/ICPS, p. 262 (10 hrs)
[33] Greek Ministry of Education, Mathematics APS/ICPS, pp. 266-267 (10 hrs)
[34] Greek Ministry of Education, Mathematics APS/ICPS, p. 270 (15 hrs)
[35] Greek Ministry of Education, Mathematics APS/ICPS, p. 292
[36] Greek Ministry of Education, Mathematics APS/ICPS, p. 279
[37] Greek Ministry of Education, Mathematics APS/ICPS, p. 253

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number in history, art and science", Interconnections with Aesthetics, History, Literature and Music.[38]

Informatics

Lower Secondary Education

Suggested interdisciplinary work projects that are interrelated with the Arts can be found in topic: “ICTs and their impact on our lives. Students choose or are encouraged to study relevant books (e.g. 'Digital World' by N. Negreponte, 'What is to come' by M. Dertouzos) and produce a group project recording their views on the impact of ICT in education, science, economy, work, culture, language and arts.[39]

Students explore the computer in society and culture along with the impact of information and communication technologies on science, art, culture, language, environment, quality of life. Understand the impact of ICTs on different social sectors (economy, culture, etc.), critically reflect on their use, assess future implications for themselves and society.[40]

On this background of the Greek national curriculum, in the remainder of this section we discuss the examples of the cases we studied.

3.2 Global Science Opera in Real Time (GSOrt)

The "Global Science Opera in Real-time " (GSOrt) initiative aims to integrate remote rural schools from Greece and the rest of Europe into the annual effort of the Global Science Opera practice. Its main aim is to encourage collaborations between multiple remote schools (more than two) using teleconference and similar online collaboration platforms to arrange and perform a joint-stage performance within a synchronous or asynchronous digital environment. Global Science Opera in Real Time (GSOrt) is a practice developed within the Global Science Opera initiative and it is focused on encouraging distant and rural schools to collaborate for preparing a scene in the Opera.

[38] Greek Ministry of Education, Mathematics APS/ICPS, p. 291
[39] Greek Ministry of Education, Informatics APS/ICPS, p. 426
[40] Greek Ministry of Education, Informatics APS/ICPS, pp. 415 and 426

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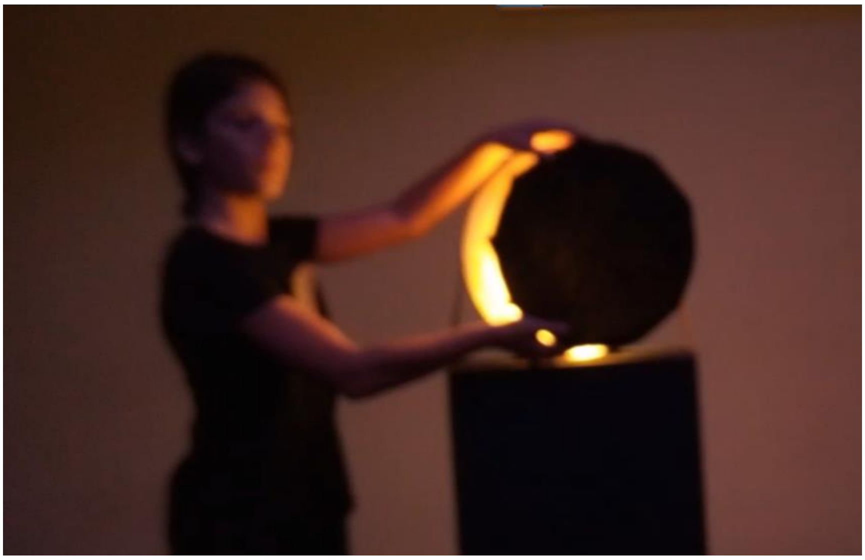

Screenshot from the filming of the Greek scene at the Gravity production, GSO 2019

The final outcome becomes part of one or more scenes in the Global Science Opera. The name "real-time" in its title is related to the use of videoconference designed in such a way so that any task of performance (e.g. stage action, music, movement, etc) is distributed in more than two places at asynchronous or, more preferably, synchronous manner (at the same time). Global Science Opera Real Time (GSOrt) is a community of European remote and rural schools working together in creating a distributed online-performance event.

In 2017 "Global Science Opera in Real Time" was selected by the Greek Ministry of Education as one the innovative good practices to be included in the "Open Book of Educational Innovation" of the European School Network (p. 145-146). http://www.eun.org/documents/411753/817341/Open_book_of_Innovational_Education.pdf

Additional observations [41]

The Global Science Opera initiative covers a wide variety of topics spanning from space education to the protection of the environment. As a yearly activity GSO allows schools to develop their own scene as part of the whole Opera and adapt its development according to the individual teacher's and school's needs. GSOrt initiative within GSO has triggered a national community of schools that contributed as

[41] Concerning the connection with informal science education, the creativity in Arts, digital fabrication, playful learning, along with todays' big challenges: Green Deal, Digitization, Health, Business and Open Schooling.

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exemplary implementation case studies described in this community: https://www.schoolofthefuture.eu/en/community/global-science-opera-real-time

3.3 LeDS

LeDS strives to deliver a holistic learning journey for students by blending students' artistic abilities with crucial technological, social and emotional skills. Through tasks such as programming suits, mastering video mapping, and orchestrating special effects, students unintentionally delve into various concepts and disciplines, spanning from mathematics and physics to computational thinking and more.

LeDS Performance with Portguese and Greek students[42]

The LeDS toolkit was created to aid students and educators in crafting digitally enhanced performances through STEAM, focusing on electronics and programming by manipulating sound, light, and movement in performance suits. The aim is to boost artistic expression while also deepening understanding of STEAM concepts in an engaging manner. While various technologies have been utilized in some performances, the LeDS toolkit emphasizes the versatile and educational aspect of programming leds with micro:bit and sensors. This approach stimulates students' creativity and imagination as they experiment with science, technology, and math concepts in microcontroller programming. It encourages them to manipulate light, sound, radio, and acceleration sensors to create "intelligent" effects that respond to

[42] LeDS Roadmap, Learning Digital Skills through Arts and Performance, p. 33 https://nuclio.org/leds-roadmap/

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environmental stimuli, such as sound, light, and movement, and can be integrated into their performances. LeDS programming is the focal point of this roadmap.

To facilitate implementation in real settings, the project has issued an online teacher's guide: https://nuclio.org/leds-roadmap/

The toolkit has been continuously adjusted based on feedback from students and teachers to meet performance requirements and cover STEAM concepts included in school curricula as comprehensively as possible.

Additional observations [43]

A suggestion for topic connected to the fabric of the suits: Construction of a suit is a collaborative work on the process of a product as a solution to a given problem e.g. designing a special suit. Extensions in technology include visual arts, computer science, and mathematics[44]. Performances can be organized within the school or in collaboration with the school's community of parents and other local stakeholders.

3.4 iMuSciCA

iMuSciCA creates and investigate innovative and enabling technologies aimed at facilitating open co-creation tools integrated into musical activities to bolster STEM education. The "iMuSciCA workbench" provides learners with opportunities to explore principles of physics, geometry, mathematics, and technology through virtually constructing musical instrument and by simulating their acoustic properties in a multimodal engaging environment. iMuSciCA teaching scenarios aim to motivate students to participate in inventive and interactive musical exercises utilizing advanced multimodal interfaces. The platform encourages students to explore fresh perspectives on science and technology fostering creative and artistic endeavors while empowering educators to develop compelling project- and problem-based STEAM learning initiatives.

[43] Concerning the connection with informal science education, the creativity in Arts, digital fabrication, playful learning, along with todays' big challenges: Green Deal, Digitization, Health, Business and Open Schooling.

[44] Indicative subject areas for lower secondary education. Greek Ministry of Education, Visual Arts APS/ICPS, page 116

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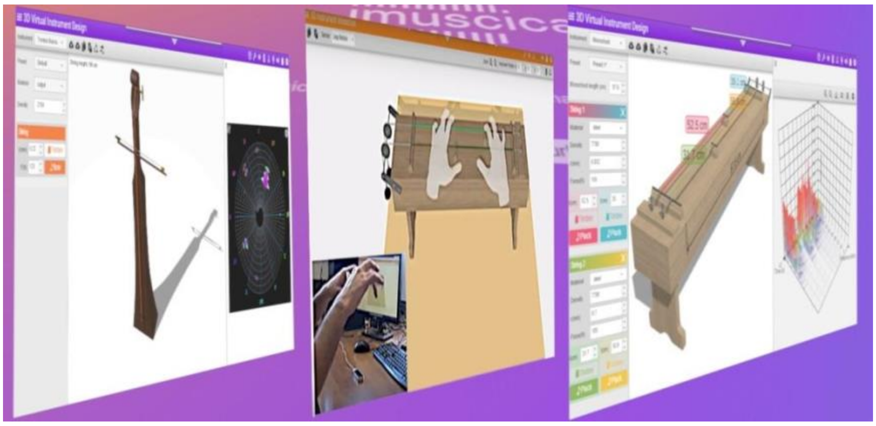

iMuSciCA. Three of the platform’s interactive environments

iMuSciCA Students' Summer Camp

A wealth of teaching scenarios spanning from late primary to late secondary education have been developed and implemented throughout the project’s lifetime. All iMuSciCA scenarios follow a modular architecture. Every scenario incorporates all Inquiry Based Science Education phases and all STEAM fields in a sequence of learning sessions spanning from at least 4 hours to longer learning periods. Teachers can implement smaller modules of lesson plans corresponding to their own needs.

The iMuSciCA online platform: https://workbench.imuscica.eu/

The learning scenarios repository: https://www.schoolofthefuture.eu/en/community/imuscica

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Awards: Educational Leaders Awards 2021

Additional observations [45]

The aim of the curriculum for music in secondary education is to combine music 'with other disciplines through the corresponding subjects' such as, inter alia, 'physics and mathematics'[46]. Also important is the recognition of pitches and the performance of intervals, including 4th and 5th clears, and the recognition of opulence based on the circle of fifths[47] . Pupils should be taught the concept of timbre[48] and concepts of harmony with regard to grades I, II, V and VI[49]. In addition, the programme can be implemented in conjunction with the research project in the first and second grades, as well as in the course: "Music Technology" in the Music High School (A-B grade), Algebra in the A' grade and the chapters on equations and equations in the Algebra B' grade course and the chapter on trigonometric equations in the course: Physics in the third grade and the chapter on wave theory.

Distinction: Paper: P. Stergiopoulos. Music and STEM. Multiple sides of the same coin. International Conference | STE(A)M educators & education. Conference proceedings STEAM on EDU 2021,, p.202-220. ISBN: 978-618-5497-24-8. (Alternative link here).

3.5 The Sound of the Earth

The "Sound of Earth" is a school activity through which students are introduced to the science behind earthquake formation and detection utilizing sonification of experimental data. Students sonify earthquake data by learning how to turn the earthquake waveforms into musical patterns and thus being able to listen to the "music" of the earth.

[45] Concerning the connection with informal science education, the creativity in Arts, digital fabrication, playful learning, along with todays' big challenges: Green Deal, Digitization, Health, Business and Open Schooling.
[46] Greek Ministry of Education, APS/ICPS, Music, Section 4.3 *Music and other subjects*, Lower Secondary.
[47] Greek Ministry of Education, APS/ICPS, Music, Section 1.2 Pitch - Melody, Secondary School
[48] Greek Ministry of Education, APS/ICPS, Music, Section 1.5 Timbre, Upper Secondary
[49] Greek Ministry of Education, APS/ICPS, Music, Section 1.7 Consonance-Harmony, Upper Secondary

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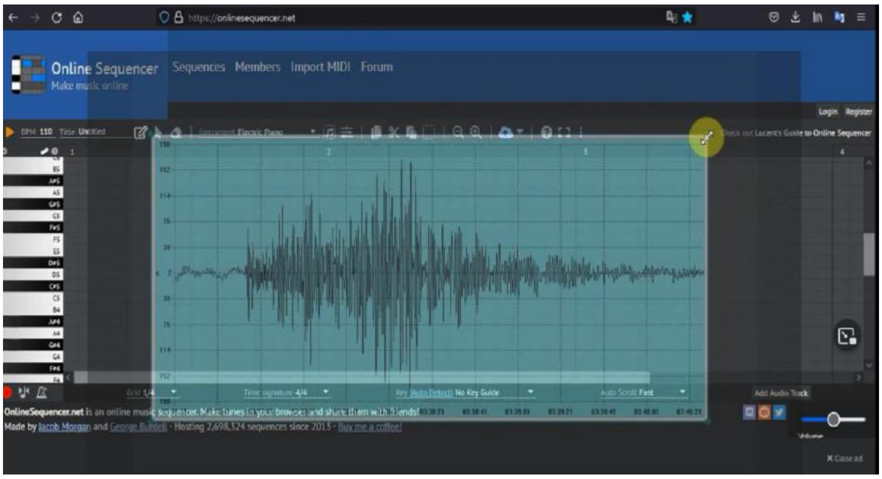

The Sound of Earth Seismogram Superimpose on Online Sequencer

The "Sound of Earth" educational scenario stimulate students' curiosity by asking, "Do earthquakes produce waves that we can hear? Can we hear the vibrations of the Earth's solid crust? Can data from a seismogram help us construct a melody coming from the vibrations of the earth?" “Sound of Earth” educational practice utilizes processing applications, that not only change the frequency of the seismic wave so that it can be perceived by the human ear but also offers a methodology matching seismic wave values with frequencies or pitch heights. In that way a seismogram is transformed into musical notation (notes) and the sound of the earth is recorded. Using digital means, the conversion of the seismogram into music can be stored and become the subject of music processing. Students learn to match a Cartesian coordinate system with the concepts of sound duration and pitch. Thus, a mapping system based on the time and extent of one, two, or more octaves of the musical chromatic scale is defined. When the seismogram is projected onto this system, the peaks resulting from its traversal from left to right, are marked. The sonification of the seismogram leads to the creation of a note sequence, which then becomes the subject of music processing through MIDI (Musical Instrument Digital Interface).

Additional observations [50]

Sound of Earth practice help students create, evaluate and revise compositions that maintain and develop musical ideas and show variety, unity and coherence.

---

[50] Concerning the connection with informal science education, the creativity in Arts, digital fabrication, playful learning, along with todays’ big challenges: Green Deal, Digitization, Health, Business and Open Schooling.

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According to the APS, students should be able to compose a set of variations on a given theme. They should familiarize themselves with the use of electronic systems (computers) to create a live performance, using sound processing hardware to change the nature of instrumental and vocal sound (computer science)[51].

Sound of Earth promotes knowledge about the physical phenomenon of the Earthquake and dealing with the public fear for it especially in regions with high earthquake activity such as in Greece. The course can successfully promote collaborative working between students as well since the result can be exported in MIDI files and be processed by a Music teacher to organize open school performances and events.

3.6 Overview of conditions and requirements

The following table presents an overview of the ways in which the above four studied cases have been integrated into the Greek curriculum.

[51] Greek Ministry of Education, Music APS/ICPS, p.348

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Table 2: integration of STEAM practices into the Greek curriculum.

Aspects of implementation Practices	Flexible Zone Scheme[52]	Teaching hours / Learning Timespan	Interdisciplinarity and collaborative teaching	Technical Prerequisites	In-School/ Out-school activities
Global Science Opera in Real Time	1,2,3	2-60	All disciplines in Sciences can collaborate with all disciplines in the Arts	Room/space of practice, Theatrical stage, Video equipment, Costume design and Fabrics, Musical instruments, ICT equipment	Film-shootings may take place inside or outside school. Visits to Science or Art Museums depending on topic
LeDS	1,2	2-30	Technology, Physical Education (Dancing teacher)	Room/space of practice, Costumes, Fabrics, Technology laboratory	Rehearsals and final performances may take place inside or outside school.
iMuSciCA	1,3	2-60	Physics, Technology, Engineering, Music, Mathematics	ICT equipment, Musical instruments, Computer Audio, Microphones	Activities take place in school. Students can also practice at home on their own time.
Sound of the Earth	1,2	2-15	Physics, Mathematics, Music	ICT equipment	Activities take place in school. Students can also practice at home on their own time.

[52] Please consult the "Interdisciplinarity" sub-section of Section 3.1.

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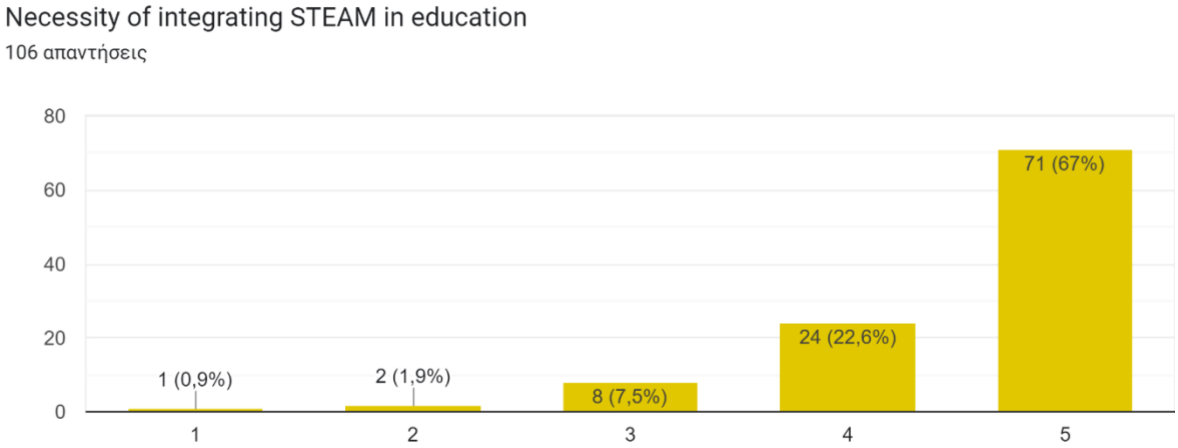
4. Conclusions and next steps

Our study confirmed stakeholders' strong belief in the necessity of integrating STEAM in education. This becomes very clearly evident in Final questionnaire responses, together with a more reserved but generally positive believe in the practice possibility of integrating STEAM in today's education.



** Likert scale: 1=Not necessary - 5=Absolutely necessary*

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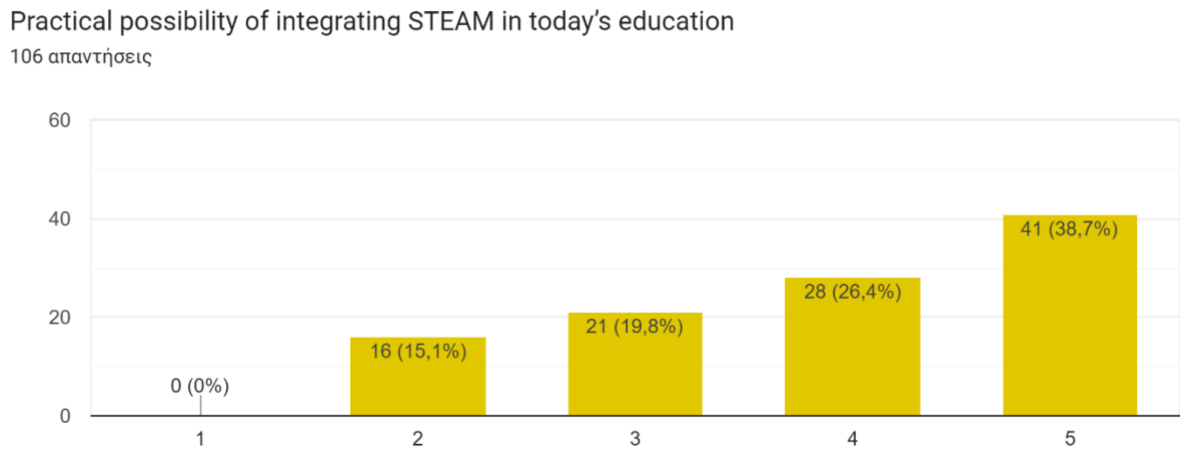

** Likert scale: 1=Not possible - 5=Absolutely possible*

The data and analysis presented in this report confirm that our informants fully confirmed the relevance of the conditions and requirements for the integration of STEAM in today's education that we set out to study. We can summarise these conditions and requirements in the following list.

Table 3: Conditions and requirements for the integration of STEAM in education

Focus on the learning and the curriculum
• Integrating curriculum areas and disciplines which, traditionally, are not connected. • STEAM practices involving arts in ways that empower students to express themselves, create, innovate. • STEAM practices that are based on addressing real-world problems and challenges. • STEAM practices that address community needs, societal concerns, and cutting-edge issues. • STEAM practices that embrace exploration, multiple pathways to knowledge, uncertainty. • STEAM practices that are practical and hands-on, involving doing and making. • STEAM practices that develop a variety of thinking skills (e.g., critical, creative, systems thinking, metacognitive). • STEAM practices that foster student's active role and ownership of the learning activity. • STEAM practices that foster collaboration among students. • STEAM practices that foster collaboration among students and teachers. • STEAM practices that foster collaboration among students, teachers, and actors from outside school. • STEAM practices that are joyful, engaging, generating intrinsic student motivation.

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- STEAM practices that empower students to develop their identities and personal meaning-making.
- STEAM practices that ensure equity and inclusion, helping all students to see themselves as successful learners.

Focus on learning assessment

- Learning assessment practices that go beyond traditional testing, to cover aspects such as student engagement, collaboration, wider competence development.
- Learning assessment helping in the ongoing evaluation and improvement of educational practices.

Focus on the curriculum frameworks and educational policy

- Teachers making independent teaching and assessment choices, within general curriculum frameworks and guidelines
- Curriculum flexibility allowing for innovative practices
- STEAM formally recognized as part of the curriculum

Focus on students

- Students' positive stance towards STEAM
- Students' previous knowledge and academic achievement
- Students' socioeconomic background
- Students' previous learning experiences

Focus on teachers

- Shift in teacher role, from instructor to facilitator of student-led learning
- Teacher's role as a change agent actively driving positive change in education
- Teacher's freedom to decide and act autonomously
- Teacher's ownership and personal investment in STEAM practices and initiatives
- Teacher's job satisfaction and motivation
- Teacher's beliefs and attitudes in relation to teaching and learning
- Teachers' positive stance towards STEAM
- Teacher's belief in their own ability to apply STEAM in practice
- Teacher's familiarity with other areas of the curriculum beyond their own main area(s) of expertise
- Teacher's familiarity with the use of technology in educational practice
- Teacher's previous teaching experiences
- Teacher's age

Focus on teacher professional development

- Appropriate pre-service teacher training
- Availability of relevant in-service teacher professional development opportunities
- In-service professional development tailored to teacher's individual needs
- Availability of concrete teacher support structures and schemes, e.g. mentorship, peer coaching, collaborative learning communities etc.

Focus on school leadership

- School leadership supportive of innovative educational practices
- School leadership trusting teacher autonomy and initiative
- School leadership shifting from top-down approaches to a collaborative vision of distributed leadership roles and shared decision-making

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- Visionary school leadership proactively creating the conditions for the integration of STEAM
- Long-term planning and commitment supporting the sustainability and scalability of STEAM innovation in the school

Focus on school climate and culture

- Encouragement of collaboration across disciplines and curriculum areas
- All disciplines valued equally, ensuring equitable access to opportunities and resources
- Encouragement of exploration, experimentation, risk-taking, learning from mistakes
- A culture of ongoing evaluation towards continuous improvement
- Teachers able to choose to implement innovations that align with their personal goals and vision
- Teachers sharing expertise, good practices, resources with their colleagues

Focus on school structure and organisation

- Availability of time within the core school schedule
- Possibility to use time flexibly within the core school schedule (e.g. restructuring the schedule)
- Possibility to use time outside the core school schedule
- Space availability within the school
- Possibility to use school space flexibly
- Possibility to use spaces outside the school
- Flexibility to support teachers' collaboration on joint teaching practices and projects
- Availability of material resources beyond traditional textbooks and equipment
- Availability of financial resources
- Budget flexibility to adapt to emerging needs

Focus on the external environment

- Authorities' (above school leadership) positive stance towards STEAM
- School's readiness to interact with external partners
- External partners' readiness to interact with the school
- Parents' active engagement with school life
- Parents' positive stance towards STEAM activities
- The school as one part of a wider collaborative learning ecosystem within the community
- Collaboration with informal/non-formal learning spaces and practitioners
- Collaboration with higher education institutions, teachers, researchers, students
- Socioeconomic, inclusivity and equity-related considerations shaping STEAM practices

Focus on recognizing the value of STEAM

- Recognition of the pedagogical value and benefits of STEAM
- Belief in the compatibility of STEAM with the existing educational culture and practices
- Compatibility of STEAM with social norms, beliefs and expectations regarding education
- Availability of evidence on the effectiveness and positive impact of STEAM practices

Nevertheless, while the vast majority of the participants considered all of the above conditions as important for the integration of STEAM in education, they attached different levels of

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“readiness” for achieving the different conditions, assessing them as more or less difficult to achieve.

The following table presents an indicative ranking of the studied conditions for the integration of STEAM in today’s education, from the most to the least difficult to achieve. This is the result of a rough calculation of a Difficulty Score based on the average of the numerified Final questionnaire responses, with the value of 3 corresponding to “Important but very difficult”, 2 for “Important but somewhat difficult”, and 3 for “Important and easy”. Further, the median of the observed values is used to identify the predominant characterisation for each item (3=Important but very difficult, 2=Important but somewhat difficult, 3=Important and easy).

It is stressed that this ranking is not intended to be used as an accurate instrument at the fine-grain level, but rather as a broader indication of the level of difficulty to achieve a certain condition, in rough comparison to other conditions that appear further down or up in the ranked list. We believe that this kind of approximate ranking can prove useful for the discussions and analyses that are to follow in the Road-STEAMer project. To facilitate the use of this ranking further, we have adopted a “traffic light” colour scheme, with red representing the most difficult conditions covering the top one third of the list, green given to the easiest conditions at the lowest third of the list, and orange characterising the conditions in the middle section of the ranking.

Table 4: Conditions for STEAM, ranked from most difficult to easiest to achieve

Area	Condition for STEAM	Ranking from most to least difficult to achieve	Difficulty score	Predominant characterisation
School structure and organisation	Availability of financial resources	1	2,55	Important but very difficult
School structure and organisation	Budget flexibility to adapt to emerging needs	2	2,48	Important but very difficult
School structure and organisation	Possibility to use time flexibly within the core school schedule (e.g. restructuring the schedule)	3	2,46	Important but very difficult
School structure and organisation	Availability of time within the core school schedule	4	2,43	Important but very difficult

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School leadership	Long-term planning and commitment supporting the sustainability and scalability of STEAM innovation in the school	5	2,34	Important but somewhat difficult
School climate and culture	All disciplines valued equally, ensuring equitable access to opportunities and resources	6	2,32	Important but somewhat difficult
School structure and organisation	Possibility to use time outside the core school schedule	7	2,31	Important but somewhat difficult
Curriculum frameworks and educational policy	Curriculum flexibility allowing for innovative practices	8	2,30	Important but somewhat difficult
School leadership	School leadership shifting from top-down approaches to a collaborative vision of distributed leadership roles and shared decision-making	9	2,29	Important but somewhat difficult
Assessment	Learning assessment practices that go beyond traditional testing, to cover aspects such as student engagement, collaboration, wider competence development.	10	2,27	Important but somewhat difficult
Teachers	Teacher's familiarity with other areas of the curriculum beyond their own main area(s) of expertise	11	2,24	Important but somewhat difficult
School leadership	Visionary school leadership proactively creating the conditions for the integration of STEAM	12	2,24	Important but somewhat difficult
Teachers	Teacher's freedom to decide and act autonomously	13	2,23	Important but somewhat difficult
Teacher professional development	In-service professional development tailored to teacher's individual needs	14	2,22	Important but somewhat difficult
External environment	Socioeconomic, inclusivity and equity-related considerations shaping STEAM practices	15	2,21	Important but somewhat difficult
School climate and culture	A culture of ongoing evaluation towards continuous improvement	16	2,21	Important but somewhat difficult
Learning and curriculum	STEAM practices that foster collaboration among students, teachers, and actors from outside school.	17	2,21	Important but somewhat difficult
Curriculum frameworks and educational policy	Teachers making independent teaching and assessment choices, within general curriculum frameworks and guidelines	18	2,21	Important but somewhat difficult
Teachers	Teacher's role as a change agent, actively driving positive change in education	19	2,18	Important but somewhat difficult
School climate and culture	Encouragement of collaboration across disciplines and curriculum areas	20	2,15	Important but somewhat difficult
School leadership	School leadership trusting teacher autonomy and initiative	21	2,15	Important but somewhat difficult
School leadership	School leadership supportive of innovative educational practices	22	2,14	Important but somewhat difficult

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Learning and curriculum	STEAM practices that ensure equity and inclusion, helping all students to see themselves as successful learners.	23	2,13	Important but somewhat difficult
School structure and organisation	Possibility to use spaces outside the school	24	2,12	Important but somewhat difficult
Curriculum frameworks and educational policy	STEAM formally recognized as part of the curriculum	25	2,11	Important but somewhat difficult
Teachers	Teacher's belief in their own ability to apply STEAM in practice	26	2,11	Important but somewhat difficult
School structure and organisation	Flexibility to support teachers' collaboration on joint teaching practices and projects	27	2,10	Important but somewhat difficult
External environment	External partners' readiness to interact with the school	28	2,10	Important but somewhat difficult
External environment	The school as one part of a wider collaborative learning ecosystem within the community	29	2,10	Important but somewhat difficult
Teachers	Shift in teacher role, from instructor to facilitator of student-led learning	30	2,09	Important but somewhat difficult
External environment	School's readiness to interact with external partners	31	2,09	Important but somewhat difficult
School structure and organisation	Possibility to use school space flexibly	32	2,08	Important but somewhat difficult
Teachers	Teacher's ownership and personal investment in STEAM practices and initiatives	33	2,07	Important but somewhat difficult
Teacher professional development	Availability of teacher support structures and schemes, e.g. mentorship, peer coaching, collaborative learning communities etc.	34	2,05	Important but somewhat difficult
External environment	Authorities' (above school leadership) positive stance towards STEAM	35	2,04	Important but somewhat difficult
Recognizing the value of STEAM	Compatibility of STEAM with social norms, beliefs and expectations regarding education	36	2,04	Important but somewhat difficult
Teachers	Teacher's job satisfaction and motivation	37	2,03	Important but somewhat difficult
School climate and culture	Teachers can choose to implement innovations that align with their personal goals and vision	38	2,02	Important but somewhat difficult
School structure and organisation	Space availability within the school	39	2,02	Important but somewhat difficult
Recognizing the value of STEAM	Belief in the compatibility of STEAM with the existing educational culture and practices	40	2,02	Important but somewhat difficult
Assessment	Learning assessment practices that help in the ongoing evaluation and improvement of educational practices.	41	2,00	Important but somewhat difficult
School climate and culture	Encouragement of exploration, experimentation, risk-taking, learning from mistakes	42	2,00	Important but somewhat difficult

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Learning and curriculum	STEAM practices integrating curriculum areas and disciplines which, traditionally, are not connected.	43	1,99	Important but somewhat difficult
Teachers	Teacher's beliefs and attitudes in relation to teaching and learning	44	1,98	Important but somewhat difficult
School structure and organisation	Availability of material resources beyond traditional textbooks and equipment	45	1,97	Important but somewhat difficult
Learning and curriculum	STEAM practices that embrace exploration, multiple pathways to knowledge, uncertainty.	46	1,95	Important but somewhat difficult
External environment	Collaboration with higher education institutions, teachers, researchers, students	47	1,95	Important but somewhat difficult
Learning and curriculum	STEAM practices that address community needs, societal concerns, cutting-edge issues.	48	1,94	Important but somewhat difficult
Teacher professional development	Appropriate pre-service teacher training	49	1,94	Important but somewhat difficult
Teacher professional development	Availability of relevant in-service teacher professional development opportunities	50	1,94	Important but somewhat difficult
Learning and curriculum	STEAM practices that empower students to develop their identities and personal meaning-making.	51	1,94	Important but somewhat difficult
Teachers	Teacher's familiarity with the use of technology in educational practice	52	1,91	Important but somewhat difficult
External environment	Collaboration with informal/non-formal learning spaces and practitioners	53	1,87	Important but somewhat difficult
External environment	Parents' active engagement with school life	54	1,86	Important but somewhat difficult
Learning and curriculum	STEAM practices involving arts in ways that empower students to express themselves, create, innovate.	55	1,82	Important but somewhat difficult
Recognizing the value of STEAM	Availability of evidence on the effectiveness and positive impact of STEAM practices	56	1,80	Important but somewhat difficult
Learning and curriculum	STEAM practices that develop a variety of thinking skills (e.g., critical, creative, systems thinking, metacognitive).	57	1,77	Important but somewhat difficult
Recognizing the value of STEAM	Recognition of the pedagogical value and benefits of STEAM	58	1,75	Important but somewhat difficult
External environment	Parents' positive stance towards STEAM activities	59	1,75	Important but somewhat difficult
Learning and curriculum	STEAM practices that foster student's active role and ownership of the learning activity.	60	1,73	Important but somewhat difficult
School climate and culture	Teachers sharing expertise, good practices, resources with their colleagues	61	1,73	Important but somewhat difficult
Teachers	Teachers' positive stance towards STEAM	62	1,71	Important but somewhat difficult
Learning and curriculum	STEAM practices that are joyful, engaging, generating intrinsic student motivation.	63	1,67	Important but somewhat difficult

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Learning and curriculum	STEAM practices that are based on addressing real-world problems and challenges.	64	1,65	Important but somewhat difficult
Learning and curriculum	STEAM practices that foster collaboration among students and teachers.	65	1,63	Important but somewhat difficult
Students	Students' positive stance towards STEAM	66	1,62	Important but somewhat difficult
Learning and curriculum	STEAM practices that are practical and hands-on, involving doing and/or making.	67	1,56	Important and easy
Learning and curriculum	STEAM practices that foster collaboration among students.	68	1,52	Important and easy

* ***Difficulty score**: Average of the observed values (3=Important but very difficult, 2=Important but somewhat difficult, 3=Important and easy). **Predominant characterisation**: Median of the observed values.*

Overall, in this report we aimed to offer a thorough examination of the practical considerations and necessities for effectively implementing STEAM practices in education. Our study viewed STEAM as an innovative approach to integrate into everyday educational settings in Europe's schools, addressing the associated conditions, challenges, and opportunities. Key aspects explored in our study include curriculum development, teacher training and professional development, and school management and leadership, all crucial components of educational innovation that must be carefully evaluated to outline essential conditions and requirements for integrating and mainstreaming STEAM approaches and practices in education.

Our analysis drew from literature reviews, workshops, and questionnaire surveys, combining the findings from the project background (deliverables D2.1, D2.2, D4.1) with insights from academic and practitioner knowledge regarding educational change and innovation introduction. Additionally, we consider the potential synergies between STEAM integration and current trends and policy issues in European education.

Moving forward, this report will guide Road-STEAMer's next steps toward developing the STEAM roadmap for science education in Horizon Europe. The Final questionnaire remains open to gather further responses, aiming to enhance our understanding of the conditions and requirements for STEAM education across a broader range of respondents and European contexts. This additional input could significantly contribute to future project deliverables, including D3.2 "Analysis of policy gaps for STEAM," D4.3 "Report on real-life use-cases," as well as D5.1 and D5.2 "STEAM roadmap for science education in Horizon Europe."

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ANNEX 1. Key STEAM notions

List of key notions that were used in the workshops, based on the discussion of the criteria for the analysis of STEAM practices (deliverable D4.1).

Collaboration

- Collaboration and relationality highlight the connections among individuals and their relationships.
- Not only teachers and students, but also external partners from various STEAM disciplines, local communities, educational stakeholders, and local citizens are essential.
- Facilitating collaboration involves engagement through acceptance, utilizing technology and game-based learning, emphasizing communication, connecting to specific art forms like music, and acknowledging the link between creativity and collaboration.
- Teachers play a facilitative role, prioritizing connected learning in classroom environments that emphasize problem-solving, authentic tasks, student choice, and technology integration.
- Teachers undertake multiple roles, serving as advisors, counselors, and guides.
- Teachers collaborate with one another, engaging in dialogue, and their manipulation of classroom environments is crucial for disciplinary inter-relationship.
- Collaboration and group working, teamwork, and interaction are sometimes listed as 21st-century skills.
- Collaboration and relationality are integral to a broader STEAM culture characterized by multi-modality.
- Expanding this understanding of 'cultures of collaboration,' authors within the posthuman paradigm also recognize collaboration and relationality not only between people but also between people and all others, such as the environment and the planet, as vital elements of STEAM practice in responding to the issues of the Anthropocene.

Disciplinary Inter-relationships

- Simply including mixed disciplines within STEAM practices involves familiarizing individuals with content outside their discipline or granting freedom to move between disciplines.
- The integration of the arts into curriculum and instruction in science, technology, engineering, and mathematics enhances interdisciplinary learning.
- More complex articulations entail forging new connections between subjects or skill areas within STEAM practice or fostering interaction between disciplines.
- Students' ability to transfer knowledge between disciplines is crucial for their educational development.
- Connection is grounded in the classroom environment, featuring problem-based learning, authentic tasks, student choice, technology integration, and teacher facilitation.
- Encompassing transdisciplinarity involves highlighting the role of transdisciplinary approaches to pedagogy.
- Encompassing interdisciplinarity topics immerses students in a diversity of knowledge across the domains of science, technology, engineering, arts, and mathematics.
- Establishing grounds for cross-disciplinary innovation fosters creative problem-solving and collaboration.

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- An even broader approach encompasses inter-, trans-, and cross-disciplinary learning, fostering holistic understanding and collaboration.
- Related to values, multi-modality, positivity, and unlearning, STEAM education promotes a holistic approach to learning.
- Driving change through a process of making, which values experimental and material agency of invention and exchange between arts and science creativities in STEAM practices, facilitates innovation.
- Developing understanding of disciplinary identities, with personal relevance informing connections between disciplines, enhances interdisciplinary learning experiences.

Arts' Contribution

- The need to address power imbalances within STEAM work, particularly regarding the arts, is a focus of this project aimed at restoring equilibrium.
- Arts are acknowledged for their contribution to the socio-cultural aspects of STEAM practice, often utilized to enhance learners' comprehension of scientific concepts and illustrate their relevance to everyday life.
- Involvement in STEAM can sometimes lead to the dilution of the arts, while STEM subjects may be superficially integrated into arts curricula.
- In the US, there's a slightly different understanding termed 'arts integration,' resembling what European arts educators recognize as 'education through the arts.'
- The arts are viewed as catalysts for fostering the creativity and innovation essential for economic competitiveness.
- They contribute to aesthetic learning intentions and provide meaning within STEAM contexts.
- The three core arts processes—creating, performing/producing, and responding/appreciating—are deemed fundamental across all domains within STEAM practices, regardless of the dominant arts disciplines.

Thinking-Making-Doing

- It's crucial to emphasize the interactivity of these practices rather than them occurring within STEAM separately or in parallel.
- Various kinds of thinking, including habits of thinking, system thinking, critical thinking, creative thinking, divergent, and convergent thinking, are integral to STEAM practices.
- STEAM practices aren't isolated 'brain-based' activities but interact with a broader set of skills, supporting soft skills and fostering the development of 21st-century skills.
- Problem-solving, encompassing creative, cognitive, and interactive aspects, is applied to hands-on design and production processes.
- Within the hands-on making and doing practices of multi-modality, unlearning, uncertainty management, and inquiry-based, real-world learning, STEAM is dynamic and engaging.
- STEAM is not merely sedentary or overly academic but embraces active participation, influenced by the 'Makers movement,' which values individuals as creators and consumers.
- Students are granted an active, constructive, and critical role in their learning within STEAM practices.
- Object-based learning, critique, exhibition, and critical making are derived from signature pedagogies in the arts, enriching STEAM practices.
- Acknowledging spaces, materials, and environments as integral elements integrates the various activities within STEAM.
- Connection-making, including with the environment, bodies, and the materiality of spaces, is vital in STEAM practices.

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- The material nature of STEAM spaces is crucial and can be arranged to promote effective practice in various ways.
- Creating spaces and materials to enhance visibility of activities for participants and the public enhances engagement with STEAM.
- Deliberate use of digital technology, such as co-creation opportunities in music, enriches STEAM activities.
- Playful engagement with STEAM via gamification using digital tools enhances learning experiences.

Creativity

- Playfulness is a key element of creative STEAM activity, fostering innovation and the production of something novel.
- The concept of flow is integral, enhancing the relationship between problem-solving and open-ended engagement with problems as facets of creativity.
- Creativity, viewed as a skill developed through STEAM practices, is considered a kind of 'doing,' closely linked to the 'thinking-making-doing' theme.
- Tools and pedagogies, such as digital technologies and design thinking, are creatively utilized within STEAM.
- Creative activities serve as a means of making connections between disciplines, supporting collaboration within STEAM.
- Creativity is both a means of supporting other features of STEAM practices and an outcome fostered by those practices.
- The connectivity fostered through creative practices in STEAM facilitates links between secondary and tertiary learning and between schools/universities and communities in Open Schooling.

Real-world Connection

- Real-world context or connection is essential, providing authenticity and purpose to the disciplinary connections being made.
- Exploration of cutting-edge issues or 'wicked problems,' such as climate change, fosters problem-solving and inquiry within STEAM.
- There's a strong link with wider EU policy, such as the EU Strategy for Enhancing Green Skills, enhancing the relevance of STEAM education.
- Civic space serves as a real-world context, facilitating connectivity between Higher Education learners and the public.
- STEAM offers a means for learners to connect their personal meaning-making within and between disciplines to the external context.
- Identity development, such as enabling girls to identify as change-makers, is fostered within STEAM education.
- Entrepreneurship is viewed as a means of connecting STEAM activity to real-world contexts, emphasizing career focus and technology use.
- STEAM education aims to develop skills that young people might need for future careers, preparing them for the challenges of the modern workforce.

Inclusion/Personalisation/Empowerment

- Inclusivity is a core principle in STEAM education, with the integration of the arts aiming to broaden the range of interests and perspectives involved, suggesting that STEAM is inherently more inclusive than STEM alone.

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- Acceptance is crucial in the design of STEAM activities, ensuring that all participants feel empowered to fully engage in every aspect of the process, regardless of their confidence levels in specific areas.
- The concepts of science capital and identity are pivotal, providing a context in which young people can develop their sense of identity within STEAM, recognizing that it is inclusive and relevant to them. Active engagement in STEAM fosters greater self-efficacy, confidence, and motivation towards learning.
- The open-ended nature of many STEAM activities, such as problem-based and inquiry learning, coupled with their real-world contexts, promotes empowerment and engagement among young people.
- Greater inclusion and empowerment within STEAM education can lead to individuals from under-represented groups, like girls, developing identities as change-makers and feeling empowered to contribute to societal progress.

Equity - an underlying value of all STEAM practices

- A values-based approach to STEAM education advocates for a departure from the dominant disciplinary approach in education.
- It entails adopting an affirmative ethical stance, promoting inclusivity and diversity within the curriculum.
- A flattened hierarchy between disciplines is recognized, with the arts regarded as core subjects alongside STEM, ensuring equitable access to time and resources for all.
- Students are empowered to take the lead in their learning, with teachers assuming the role of facilitators and guides, fostering a more equitable power relation in the classroom.
- Equity emerges as a potential outcome of STEAM education, particularly in the production of socially equitable responses to global challenges, although this is more aspirational than evidence-based at present.
- Equity is identified as a key feature of STEAM practices, more commonly observed in tertiary-level education compared to secondary education.

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ANNEX 2. Exploratory questionnaire

The "Questionnaire exploring conditions and requirements for the effective integration of STEAM in education" ("Exploratory questionnaire")

Your position/role:

Have you participated as an educator in activities that promote STEAM education?

Yes No

STEAM education is adequately represented in the school curriculum.

Absolutely disagree 1 2 3 4 5 Absolutely agree

STEAM education must by definition take place outside of school hours, because it is not compatible with school education.

Absolutely disagree 1 2 3 4 5 Absolutely agree

STEAM education can de facto only take place outside of the school curriculum, because there is no space and time for it in the school reality.

Absolutely disagree 1 2 3 4 5 Absolutely agree

My teaching incorporates the educational approach of STEAM.

Absolutely disagree 1 2 3 4 5 Absolutely agree

The STEAM activities I implement are closely linked to the school's curriculum.

Absolutely disagree 1 2 3 4 5 Absolutely agree

The STEAM activities I implement take place:

Mainly during school hours

Mainly outside of school hours

In the context of a group, afternoon activities, etc.

Out of school

I do not implement STEAM activities.

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Within a school year, the STEAM activities I implement last:

1-4 teaching hours

5-12 teaching hours

13-60 teaching hours

Over 60 teaching hours

I do not implement STEAM activities.

How many hours of preparation does the STEAM activity you do require of you per school year?

1-4 hours

5-12 hours

13-60 teaching hours

Over 60 hours

I do not implement STEAM activities.

My school encourages doing STEAM activities.

Absolutely disagree 1 2 3 4 5 Absolutely agree

The conditions for doing STEAM activities at my school are favorable.

Absolutely disagree 1 2 3 4 5 Absolutely agree

My colleagues are available to collaborate on the development and implementation of STEAM activities.

Absolutely disagree 1 2 3 4 5 Absolutely agree

Parents and the external environment of my school favor the implementation of STEAM activities.

Absolutely disagree 1 2 3 4 5 Absolutely agree

I receive adequate training on teaching with the methodology of STEAM

Absolutely disagree 1 2 3 4 5 Absolutely agree

I am sufficiently informed about training opportunities on teaching with the methodology of STEAM

Absolutely disagree 1 2 3 4 5 Absolutely agree

If you are not developing STEAM activities, what are the reasons for this? (you can choose multiple answers)

I don't know the educational approach of STEAM well enough

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My colleagues find it difficult to work together to develop STEAM activities

The school is a “suffocating” environment and does not allow the development of STEAM activities

I don't have the technical support needed

I don't have the necessary training

I'm not into STEAM and the question doesn't concern me

Other:

The Performing Arts (Theatre, Music, Dance), Film and other related Art forms are adequately represented in the school's existing curriculum.

Absolutely disagree 1 2 3 4 5 Absolutely agree

Visual Arts (Painting, Sculpture) and other related Art forms are adequately represented in the school's existing curriculum.

Absolutely disagree 1 2 3 4 5 Absolutely agree

The “A” in the STEAM activities I implement is related to the Visual Arts.

Absolutely disagree 1 2 3 4 5 Absolutely agree

The “A” in the STEAM activities I implement is related to the Performing Arts.

Absolutely disagree 1 2 3 4 5 Absolutely agree

The “A” in STEAM better corresponds to the words “All disciplines” to include all other areas of the curriculum beyond STEM, not just the Arts.

Absolutely disagree 1 2 3 4 5 Absolutely agree

The “A” of STEAM plays a role in my teaching which is:

Primary

Secondary

Balanced

Indifferent / Opportunistic

“A” in the STEAM activities I do (multiple choices allowed):

Was the trigger for their creation

Is a fundamental element for their implementation

Arises through their implementation, without being a central element

Is not a decisive element for their implementation

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I don't do STEAM activities

The fact that there is "A" in the STEAM educational approach, favors:

Better collaboration in learning

Absolutely disagree 1 2 3 4 5 Absolutely agree

Interconnection of sciences and disciplines, interdisciplinary approaches

Absolutely disagree 1 2 3 4 5 Absolutely agree

Synthesis of thinking, making and doing

Absolutely disagree 1 2 3 4 5 Absolutely agree

Creativity in learning

Absolutely disagree 1 2 3 4 5 Absolutely agree

Connecting learning to the real world

Absolutely disagree 1 2 3 4 5 Absolutely agree

Inclusion and empowerment of all students

Absolutely disagree 1 2 3 4 5 Absolutely agree

Indicative results from the Exploratory questionnaire

Indicative ranking of agreement statements

Statement	Mean	Median	Ranking
The fact that there is the "A" in the educational approach of STEAM favours creativity in learning	4,32	5	1
The fact that there is the "A" in the educational approach of STEAM favours the inclusion and empowerment of all students	4,24	4	2
The fact that there is the "A" in the educational approach of STEAM favours the synthesis of thought, doing and making	4,08	4	3
The fact that there is the "A" in the educational approach of STEAM favors better collaboration during learning	4,03	4	4
The fact that there is the "A" in the educational approach of STEAM favours the interconnection of disciplines and interdisciplinary approaches	4,03	4	5

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Statement	Mean	Median	Ranking
The fact that there is the "A" in the STEAM educational approach favours the connection of learning with the real world	4,03	4	6
The “A” of STEAM best corresponds to the phrase “All disciplines” to include all other areas of the curriculum beyond STEM, not just the Arts.	3,38	3	7
The “A” in the STEAM activities I implement is related to the Visual Arts.	3,24	4	8
My teaching incorporates the STEAM educational approach.	3,19	3	9
Parents and the extracurricular environment of my school favour the implementation of STEAM activities.	3,08	3	10
My school encourages doing STEAM activities.	3,03	3	11
I am sufficiently informed about training opportunities on teaching with the STEAM methodology	3,00	3	12
The STEAM activities I implement are closely linked to the school's curriculum.	2,95	3	13
The “A” in the STEAM activities I implement is related to the Performing Arts.	2,92	3	14
The conditions for doing STEAM activities at my school are favourable.	2,78	3	15
My colleagues are available to collaborate on the development and implementation of STEAM activities.	2,78	3	16
Visual Arts (Painting, Sculpture) and other related Art forms are adequately represented in the school's existing curriculum.	2,76	3	17
I receive adequate training on teaching with the STEAM methodology	2,62	3	18
The Performing Arts (Theatre, Music, Dance), Film and other related Art forms are adequately represented in the school's existing curriculum.	2,59	3	19
STEAM education is adequately represented in the school curriculum.	2,35	2	20
STEAM education can de facto only take place outside of the school curriculum, because there is no space and time for it in the school reality.	1,89	1	21
STEAM education must by definition take place outside of school hours, because it is not compatible with school education.	1,65	1	22

**Likert scale: 1=Absolutely disagree - Absolutely agree*

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ANNEX 3. Barriers questionnaire

The "Questionnaire on barriers to the effective integration of STEAM in education" ("Barriers questionnaire")

Your background (choose all that apply):

School teacher

Education leader (e.g., school head, subject head, local educational authority...)

Other educator (e.g., higher education, non-formal/informal learning...)

Parent of school student

Researcher

Educational policymaker

Other:

STEAM and you (choose all that apply):

I apply STEAM in my practice

I do research in STEAM

I am interested in STEAM

Other:

Challenges for the integration of STEAM in science education

1. Institutional and Structural Barriers:

Traditional Educational Paradigm: The traditional education system is often rigid and resistant to change, favoring established practices and methodologies.

Least important barrier 1 2 3 4 5 Most important barrier

Lack of Leadership and Support: Educational institutions often lack strong leadership and support for innovation, with decision-making processes favoring status quo.

Least important barrier 1 2 3 4 5 Most important barrier

Financial Resources and Infrastructure: Implementing innovative educational approaches often requires significant financial resources, which may not be readily available to schools and institutions.

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Least important barrier 1 2 3 4 5 Most important barrier

Curriculum and Assessment Frameworks: Existing curriculum and assessment frameworks may not align with innovative approaches, creating challenges in implementing and evaluating change.

Least important barrier 1 2 3 4 5 Most important barrier

2. Teacher Training and Professional Development:

Teacher Expertise and Capacity: Many teachers may not have the necessary expertise and training to effectively implement innovative pedagogical practices.

Least important barrier 1 2 3 4 5 Most important barrier

Fear of Change and Resistance to New Approaches: Teachers may be resistant to change and unfamiliarity with new technologies or teaching methodologies.

Least important barrier 1 2 3 4 5 Most important barrier

Time and Resources for Professional Development: Integrating innovation into teaching practice requires dedicated time and resources for professional development and training.

Least important barrier 1 2 3 4 5 Most important barrier

3. Cultural and Societal Perspectives:

Traditional Learning Values and Practices: Societal expectations and traditional views on education may hinder the adoption of innovative approaches.

Least important barrier 1 2 3 4 5 Most important barrier

Parental Concerns and Misconceptions: Parents may be apprehensive about new teaching methods or technologies, fearing that they may harm their children's education.

Least important barrier 1 2 3 4 5 Most important barrier

Lack of Public Awareness and Support: There may be a lack of awareness and support from the public and policymakers for innovative educational reforms.

Least important barrier 1 2 3 4 5 Most important barrier

Ranking the challenges for the integration of STEAM in science education

	Institutional and Structural Barriers	Teacher Training and Professional Development	Cultural and Societal Perspectives
1st most important			

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2nd most important			
3rd most important			

The first thing that comes to your mind when you think about the challenges for the integration of STEAM in science education (write as much or as little as you like):

Any other thoughts about the integration of STEAM in science education? (write as much or as little as you like):

Indicative results from the Barriers questionnaire

Indicative ranking of Likert-scale statements

Barrier	Mean	Median	Ranking
Time and resources for professional development	4,30	5	1
Financial resources and infrastructure	4,03	4	2
Fear of change and resistance to new approaches	3,95	4	3
Traditional educational paradigm	3,84	4	4
Teacher expertise and capacity	3,68	4	5
Curriculum and assessment frameworks	3,58	4	6
Lack of leadership and support	3,51	4	7
Traditional learning values and practices	3,35	4	8
Lack of public awareness and support	3,35	3	9
Parental concerns and misconceptions	2,59	3	10

**Likert scale: 1=Least important barrier - 5=Most important barrier*

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ANNEX 4. Final questionnaire

The "Final questionnaire on the conditions and requirements for the effective integration of STEAM in education" ("Final questionnaire")

INTRODUCTION

We are researching the conditions and requirements for the effective introduction of STEAM (Science, Technology, Engineering, Arts, Mathematics) practices in education, and we would like to know what you think about the conditions and requirements for this.

We use the term "STEAM" to refer to a range of educational approaches that integrate Science, Technology, Engineering, Arts, and Mathematics. While there is not only one way of doing this, in the Road-STEAMer project we refer to the following elements that are often present in STEAM practices: collaboration between students, teachers, and other actors; crossing disciplinary boundaries; fostering creativity; encouraging thinking, making, and doing; focusing on practical applications and addressing real-world issues; ensuring inclusion, personalization, learner empowerment, and equity.

It would help us a lot in our research if you could answer a few questions we would like to ask you, in this online questionnaire. It should not take you long (approximately 10-15 minutes), and your answers will be of great value to us.

No reply is mandatory, so you can skip questions you don't feel like answering. Nevertheless, please try answering all of them, if possible.

Your responses are confidential and completely anonymous.

Thank you!

YOUR RIGHTS

[Informed consent statements]

ABOUT YOU

The country where you live:

About you *(Select all that apply)*:

- Teacher in school education
- Teacher in higher education
- Non-formal/informal learning educator or similar
- In educational leadership (e.g., head, supervisor, etc.)
- Teacher trainer
- Educational researcher
- In educational policy making
- Student's parent
- Student
- Scientist / in scientific activity

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- Artist / in artistic activity
- Creative professional / in creative industry
- Businessperson / entrepreneur
- Active in civil society (e.g., NGO, active citizenship, etc)
- Other/details:

You and STEAM education *(Select all that apply)*:

- I apply, or have applied, STEAM education in practice
- I do, or have done, research on STEAM education
- I am interested in STEAM education
- Other/details:

Conditions and requirements for the introduction of STEAM in education

To answer the questions below, please think of the educational context you are most familiar with, in the country where you live.

Focus on the curriculum

*In your view, are the following **important conditions** for the introduction of STEAM in education? And are they **easy or difficult to achieve** for the introduction of STEAM in today's education?*

Integrating curriculum areas and disciplines which, traditionally, are not connected.

> *Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM*

STEAM practices involving arts in ways that empower students to express themselves, create, innovate.

> *Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM*

STEAM practices that are based on addressing real-world problems and challenges.

> *Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM*

STEAM practices that address community needs, societal concerns, and cutting-edge issues.

> *Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM*

STEAM practices that embrace exploration, multiple pathways to knowledge, uncertainty.

> *Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM*

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STEAM practices that are practical and hands-on, involving doing and making.

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

STEAM practices that develop a variety of thinking skills (e.g., critical, creative, systems thinking, metacognitive).

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

STEAM practices that foster student's active role and ownership of the learning activity.

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

STEAM practices that foster collaboration among students.

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

STEAM practices that foster collaboration among students and teachers.

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

STEAM practices that foster collaboration among students, teachers, and actors from outside school.

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

STEAM practices that are joyful, engaging, generating intrinsic student motivation.

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

STEAM practices that empower students to develop their identities and personal meaning-making.

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

STEAM practices that ensure equity and inclusion, helping all students to see themselves as successful learners.

Focus on learning assessment

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*In your view, are the following **important conditions** for the introduction of STEAM in education? And are they **easy or difficult to achieve** for the introduction of STEAM in today's education?*

Learning assessment practices that go beyond traditional testing, to cover aspects such as student engagement, collaboration, wider competence development.

> *Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM*

Help in the ongoing evaluation and improvement of educational practices.

> *Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM*

Focus on students

*In your view, is the following an **important condition** for the introduction of STEAM in education? And is it **easy or difficult to achieve** for the introduction of STEAM in today's education?*

Students' positive stance towards STEAM

> *Important and easy – Important but somewhat difficult – Important but very difficult – Not important for STEAM*

Are the following aspects important factors for the effective integration of STEAM in education?

Students' previous knowledge and academic achievement

> *Not important 1 2 3 4 5 Very important*

Students' socioeconomic background

> *Not important 1 2 3 4 5 Very important*

Students' previous learning experiences

> *Not important 1 2 3 4 5 Very important*

Focus on teachers

*In your view, are the following **important conditions** for the introduction of STEAM in education? And are they **easy or difficult to achieve** for the introduction of STEAM in today's education?*

Shift in teacher role, from instructor to facilitator of student-led learning

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Important and easy – Important but somewhat difficult – Important but very difficult – Not important for STEAM

Teacher's role as a change agent actively driving positive change in education

Important and easy – Important but somewhat difficult – Important but very difficult – Not important for STEAM

Teacher's freedom to decide and act autonomously

Important and easy – Important but somewhat difficult – Important but very difficult – Not important for STEAM

Teacher's ownership and personal investment in STEAM practices and initiatives

Important and easy – Important but somewhat difficult – Important but very difficult – Not important for STEAM

Teacher's job satisfaction and motivation

Important and easy – Important but somewhat difficult – Important but very difficult – Not important for STEAM

Teacher's beliefs and attitudes in relation to teaching and learning

Important and easy – Important but somewhat difficult – Important but very difficult – Not important for STEAM

Teachers' positive stance towards STEAM

Important and easy – Important but somewhat difficult – Important but very difficult – Not important for STEAM

Teacher's belief in their own ability to apply STEAM in practice

Important and easy – Important but somewhat difficult – Important but very difficult – Not important for STEAM

Teacher's familiarity with other areas of the curriculum beyond their own main area(s) of expertise

Important and easy – Important but somewhat difficult – Important but very difficult – Not important for STEAM

Teacher's familiarity with the use of technology in educational practice

Important and easy – Important but somewhat difficult – Important but very difficult – Not important for STEAM

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Are the following aspects important factors for the effective integration of STEAM in education?

Teacher's previous teaching experiences

Not important 1 2 3 4 5 Very important

Teacher's age

Not important 1 2 3 4 5 Very important

Based on what you consider most appropriate for the integration of STEAM in today's education, you would prefer:

STEAM activities implemented mainly by STEM teachers (science, technology, engineering, maths)

Not preferable 1 2 3 4 5 strongly preferred

STEAM activities implemented mainly by arts and humanities teachers

Not preferable 1 2 3 4 5 strongly preferred

STEAM activities implemented by all teachers

Not preferable 1 2 3 4 5 strongly preferred

STEAM activities implemented mainly by teachers with a STEAM specialization

Not preferable 1 2 3 4 5 strongly preferred

Focus on teacher professional development

In your view, are the following ***important conditions*** *for the introduction of STEAM in education? And are they* ***easy or difficult to achieve*** *for the introduction of STEAM in today's education?*

Appropriate pre-service teacher training

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

Availability of relevant in-service teacher professional development opportunities

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

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In-service professional development tailored to teacher's individual needs

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

Availability of concrete teacher support structures and schemes, e.g. mentorship, peer coaching, collaborative learning communities etc.

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

Focus on school leadership

In your view, are the following ***important conditions*** *for the introduction of STEAM in education? And are they* ***easy or difficult to achieve*** *for the introduction of STEAM in today's education?*

School leadership supportive of innovative educational practices

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

School leadership trusting teacher autonomy and initiative

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

School leadership shifting from top-down approaches to a collaborative vision of distributed leadership roles and shared decision-making

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

Visionary school leadership proactively creating the conditions for the integration of STEAM

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

Long-term planning and commitment supporting the sustainability and scalability of STEAM innovation in the school

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

Focus on school climate and culture

In your view, are the following ***important conditions*** *for the introduction of STEAM in education? And are they* ***easy or difficult to achieve*** *for the introduction of STEAM in today's education?*

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Encouragement of collaboration across disciplines and curriculum areas

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

All disciplines valued equally, ensuring equitable access to opportunities and resources

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

Encouragement of exploration, experimentation, risk-taking, learning from mistakes

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

A culture of ongoing evaluation towards continuous improvement

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

Teachers can choose to implement innovations that align with their personal goals and vision

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

Teachers sharing expertise, good practices, resources with their colleagues

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

Focus on school structure and organisation

In your view, are the following ***important conditions*** *for the introduction of STEAM in education? And are they* ***easy or difficult to achieve*** *for the introduction of STEAM in today's education?*

Availability of time within the core school schedule

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

Possibility to use time flexibly within the core school schedule (e.g. restructuring the schedule)

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

Possibility to use time outside the core school schedule

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Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

Space availability within the school

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

Possibility to use school space flexibly

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

Possibility to use spaces outside the school

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

Flexibility to support teachers' collaboration on joint teaching practices and projects

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

Availability of material resources beyond traditional textbooks and equipment

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

Availability of financial resources

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

Budget flexibility to adapt to emerging needs

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

Focus on the external environment

*In your view, are the following **important conditions** for the introduction of STEAM in education? And are they **easy or difficult to achieve** for the introduction of STEAM in today's education?*

Authorities' (above school leadership) positive stance towards STEAM

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

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School's readiness to interact with external partners

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

External partners' readiness to interact with the school

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

Parents' active engagement with school life

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

Parents' positive stance towards STEAM activities

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

The school as one part of a wider collaborative learning ecosystem within the community

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

Collaboration with informal/non-formal learning spaces and practitioners

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

Collaboration with higher education institutions, teachers, researchers, students

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

Socioeconomic, inclusivity and equity-related considerations shaping STEAM practices

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

Focus on the curriculum and educational policy

*In your view, are the following **important conditions** for the introduction of STEAM in education? And are they **easy or difficult to achieve** for the introduction of STEAM in today's education?*

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Teachers making independent teaching and assessment choices, within general curriculum frameworks and guidelines

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

Curriculum flexibility allowing for innovative practices

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

STEAM formally recognized as part of the curriculum

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

Based on what you consider most appropriate for the integration of STEAM in today's education, you would prefer:

STEAM practices integrated mainly in STEM curriculum areas (science, technology, engineering, maths)

Not preferable 1 2 3 4 5 strongly preferred

STEAM practices integrated mainly in arts and humanities curriculum areas

Not preferable 1 2 3 4 5 strongly preferred

STEAM practices integrated across the curriculum

Not preferable 1 2 3 4 5 strongly preferred

STEAM as a separate curriculum area

Not preferable 1 2 3 4 5 strongly preferred

Focus on recognizing the value of STEAM

*In your view, are the following **important conditions** for the introduction of STEAM in education? And are they **easy or difficult to achieve** for the introduction of STEAM in today's education?*

Recognition of the pedagogical value and benefits of STEAM

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

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Belief in the compatibility of STEAM with the existing educational culture and practices

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

Compatibility of STEAM with social norms, beliefs and expectations regarding education

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

Availability of evidence on the effectiveness and positive impact of STEAM practices

Important and easy - Important but somewhat difficult - Important but very difficult - Not important for STEAM

Your own stance to STEAM education

Necessity of integrating STEAM in education

Not necessary 1 2 3 4 5 Absolutely necessary

Practical possibility of integrating STEAM in today's education

Not possible 1 2 3 4 5 Absolutely possible

Your final comments

The first thing that comes to your mind when you think about the challenges for the integration of STEAM in science education:

Any other thoughts about the integration of STEAM in education?

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