WP2 STEAM context, concepts and conditions

Deliverable 2.1 Socio-economic context and relevant needs

Deliverable 2.1

Grant Agreement Number	101058405
Project Acronym	Road-STEAMer
Project title	Developing a STEAM Roadmap for Science Education in Horizon Europe
Start date of the project	01.09.2022
Duration of the project	36 months
Due Date of Deliverable	28/02/2023
Version	Version 2 - resubmission following review report
Dissemination Level	Public
Project website address	www.road-steamer.eu

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Abbreviation	Description
EA	Ellinogermaniki Agogi
EC	European Network Science Centres and Museums (Ecsite)
ENG	Engineering Ingegneria Informatica
ESHA	European School Heads Association
ESIR	Economic and Societal Impact of Research
EU	European Union
GDPR	General Data Protection Regulation
ICT	Information and Communications Technology
LC	The Lisbon Council for Economic Competitiveness and Social Renewal asbl
LLL	Lifelong Learning
MOP	Mission-Oriented Policy
NASEM	National Academies of Sciences, Engineering, and Medicine
OECD	Organisation for Economic Co-operation and Development
PAN	Panteion
PMB	Project Management Board
PO	Politecnico di Milano
R&D	Research and Development
STEAM	Science, Technology, Engineering, Arts and Mathematics

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Abbreviation	Description
SV	Science View
TIMSS	National Center for Education Statistics
TR	TRACES
UM	University of Malta
UoE	The University of Exeter
VET	Vocational Education and Training
WP	Work Package
ZSI	Zentrum für Soziale Innovation

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Revision History

Revision	Date	Author	Organisation	Description
0.1	15.09.2022	Elisabeth Unterfrauner	ZSI	Initial draft
0.2	30.11.2022	Elisabeth Unterfrauner (ZSI), Claudia Magdalena Fabian (ZSI), Lucy Yeomans (UoE), Iro Voulgari (UM), Menelaos Sotiriou (SV), Dimitrios Sotiropoulos (SV)	ZSI, UoE, UM, SV	Contributions by partners
0.3	28.12.2022	Stephanos Cherouvis (ECSITE), Pavlos Koulouris (EA)	EA	Contributions by all remaining partners integrated
0.4	19.01.2023	Elisabeth Unterfrauner (ZSI), Claudia Magdalena Fabian (ZSI)	ZSI	Adding the results from the online co-creation workshop on 19. January 2023
0.5	31.01.2023	Sabrina Bresciani (Polimi)	Polimi	Conclusions and recommendations
0.6	15.02.2023	Vasileios Liakopoulos (EA)	EA	Reviewers' comments
1.0	16.02.2023	E. Unterfrauner, C.M. Fabian	ZSI	Revision, final formatting and pdf submission
2.0	14.02.2024	E. Unterfrauner, C.M. Fabian	ZSI	Revision after reviewer's feedback, rework on methodology section, final formatting and PDF submission

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Abstract

Deliverable D2.1 of the Road-STEAMer project as part of WP2 with a wider perspective on contexts and conditions for STEAM, focuses specifically on the socio-economic context and needs for STEAM in education in Europe. The exploration of these needs and contexts is methodologically based, firstly, on desk research including literature review and secondary data analysis and secondly, on a co-creation workshop with consortium members.

The results indicate that STEAM participation and achievements are still heavily impacted by the family's socio-economic condition as well as their educational and science capital. Intersectional aspects such as gender, migration background, add to the under-representation of diverse groups. Thus, there is a need for widened socio-cultural 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, the shift is towards a "hostile obstacle course" placing the focus away from individuals onto systematic barriers at different levels.

In times of the COVID-19 pandemic 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 understanding of science by society. Different mechanisms can improve the attitude toward science and interest in science; some of these are (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, 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.

The report concludes with recommendations on overcoming some of the identified challenges and fulfilling the needs for STEAM.

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1. Introduction

1.1 About Road-STEAMer

The overall aim of the 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 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

D2.1 represents the first of three reports in WP 2 (STEAM context, concepts, and conditions) as an important conceptual layer in the Road-STEAMer project. While D2.1 focuses on the socio-economic context and need for STEAM, D2.2 develops a conceptual framework for STEAM, and D2.3 finally distils requirements and conditions for effective STEAM education. Each task and respective deliverable builds upon each other and its outcomes are important for the Work packages 3, 4, 5 and 6. The outputs are each complemented with the contributions from stakeholders in co-creation workshops.

The report aims to explore wider socio-economic contexts and needs for STEAM, including different perspectives such as societal needs, the need for inclusion and diversity in STEAM education, fostering the interest in STEAM as (a) school subject(s), and related career choices. While we do not claim to provide a complete picture of all STEAM needs in Europe, we provide deeper insights on specific needs like inclusivity aspects in STEAM and deconstructing gender stereotypes and learning for younger and older generations.

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The exploration of these needs and contexts is methodologically based, firstly, on desk research including literature reviews and secondary data analysis (where feasible) and secondly, on a co-creation workshop with consortium members (cf. WP1).

Desk research builds the basis of the exploration of STEAM needs and socio-economic contexts. The resulting preliminary findings are further complemented with details and validated to come to the final identification of STEAM needs and contexts in a co-creation workshop with stakeholders and consortium members.

The report is structured along four sections.

The introduction section is followed by section 2, Methodology, briefly describing how we gained the findings based on desktop research and the co-creation workshop.
In section 3 we discuss the findings: firstly, the findings through desktop research, and secondly, the findings as validated and complemented through the online co-creation workshop. With section 4 we conclude the report by summarising the main findings and proposing some recommendations to take these contexts and needs into account in the other strand of work in Road-STEAMer.

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2. Methodology

Deliverable 2.1 is based firstly on literature review and secondly a co-creation workshop with consortium partners.

2.1 Literature review

The methodology employed for Report D2.1 involved a comprehensive thematic literature review, combining information gathered from seven accessible literature databases such as Google Scholar, JSTOR, Elsevier, RefSeek, Unesco, OECD, and Eurydice. The review was conducted collaboratively by consortium partners, each assigned to specific subsections of the desktop research findings. The criteria for source selection were meticulously defined to ensure the quality and relevance of the literature.

Inclusion Criteria for Source Selection:

a. Temporal Relevance: References to literature were restricted to publications within the last 15 years, with exceptions for enduring state-of-the-art publications.

b. Citation Style: All references adhered to the APA style, maintaining consistency and scholarly rigour.

c. Language Diversity: While references to publications in different languages were accepted, direct citations needed to be translated for uniform understanding.

d. Inclusion of Secondary Data: The methodology allowed for the inclusion of secondary data, broadening the scope of insights.

e. Documentation of Keywords: A systematic documentation of keywords used in databases was maintained to enhance transparency and replicability.

f. Have the full text available

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The following table provides an overview of the different desktop research sections, responsible partners and keywords applied in the literature search.

Table 1: Literature review along keywords search in literature databases

Section (partner responsible)	Keywords and literature database
3.1.1 Socio-economic context (ZSI)	STEM inequality, socio-economic background/status, educational capital, science capital - Google Scholar
3.1.2 Need for a science literate society (EA)	Science literacy, scientific literacy, need for a science literate society - Google Scholar
3.1.3 Need for highly educated scientists (SV)	Education, highly educated scientists, career uptake, STEM/STEAM career, gender-science stereotypes, motivation, role models (in science), (students) career awareness, changing attitudes (in secondary education), awareness, lack of interest (about science), student's view (opinion about) scientists and science, real life problems and science, future lives, underrepresented minorities in education, gap / equity, STEM/STEAM teaching. Academic Searching: Google Scholar, Elsevier, RefSeek Web/Organisations sites searching: Unesco, OECD, Eurydice
3.1.4 Needs from industry (UM)	("STEAM" OR "STEM") AND (indust* OR compan*) AND skill* - Google Scholar
3.1.5 Need for widened socio-cultural participation and deconstruction of STEAM stereotypes (UoE)	Inclusive pedagogies, STEAM OR STEM or science, diversity, socio-economic status, working-class, girl* OR female OR wom*n, ethnic minorit*, participation, engagement - Google Scholar
3.16 Need to draw the right lessons from C19 (EC)	STEM education in (or) and COVID19, Education disrupted or disruption in (or) during COVID19, Covid19 Lessons Education - Google Scholar
3.1.7 Interconnections between needs and policy (ZSI, EA)	History of EU, EU policy areas, EU policy areas and STEAM, EU innovation policy - Google Scholar

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In total, this process generated 136 scientific sources that met the inclusion criteria. Seven of these sources contained analysis of EU and international data Eurobarometer, PISA, and further OECD reports.

2.2 Co-creation workshop

Subsequent to the desktop research, an online co-creation workshop was conducted on January 19, 2023, involving consortium members. The primary goal was to complement and validate the findings from the literature review by integrating diverse perspectives from consortium members, representing various stakeholder groups and fields of expertise. Informed by both desk research and additional considerations, the consortium aimed to formulate recommendations on meeting the identified needs for STEAM education. This approach ensures a comprehensive and well-rounded understanding of the subject, enriching the report with practical insights and collective expertise.
The workshop was organised jointly with the UoE team for optimal synergy effects between tasks T2.1 and T4.1 (belonging to work packages WP2 and WP4 respectively).

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3. Results

The following subsection (section 3.1) is dedicated to the desktop research results, followed by the co-creation workshop results (section 3.2).

3.1 Desktop research results

3.1.1. Socio-economic context of STEM (and STEAM) learning

This section describes the wider socio-economic context of STEAM on different levels. Firstly, we briefly explore the national expenditure on education of Member States, and then secondly, reflect on arguments that relate to the socio-economic dimension of STEAM education. Thirdly and most importantly, we analyse the relation of socio-economic status of families and their educational and science capital in relation to STEAM participation and attainment.

Public expenditure on education

Member States spent on average 5% of their GDP on education, from pre-primary to tertiary education, with Iceland, Sweden and Belgium spending the highest shares of GDP with up to 7.7 %. According to the OECD, countries on average spend a total of USD 105,500 to educate a student from the age of 6 to the age of 15 (OECD, 2022). Worldwide, there is quite a difference in the budget that is spent on education. For instance, Austria, Luxembourg, and Norway spend as much as over USD 150 000 per student.

Although most EU countries are committed to a high-quality education with considerable investments, the outcomes of education are not perceived as satisfactory. The Eurobarometer survey on the 'European Area of Skills and Qualifications' (The European Education Area - Mai 2018 - Eurobarometer Survey, n.d.) indicates that about a quarter of EU respondents feel that their education has not provided them with sufficient skills to find a job in line with their qualifications. As Pisa results suggest, students in countries with higher GDP also achieve higher results in PISA scores (OECD, 2019). Thus, the investment in education pays off to a certain degree. When expenditure per student education increases, so does also the average score in PISA but there are limits to this correlation. The scores increase until a plateau is reached and after that diminish. Expenditure accounts for 49% of the variation in mean performance between countries/ economies, indicating that there are of course other factors than GDP and the investment in education impacting the PISA performance. Estonia, for instance, which spends less than the OECD average on education achieves one of the highest scores in PISA in Europe. The latest Pisa report concludes that “while education needs to be adequately resourced, and is often under-resourced in developing countries, a high level of spending per student is not required to achieve excellence in education” (OECD, 2019, p. 66).

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There are multiple factors playing a role when it comes to school performance in mathematics and science subjects beside the public investment in education. The socio-economic status of and the educational capital of families, and society at large supporting (lifelong)learning and offering opportunities for informal learning play an important role. Additionally, schools are faced with a diversity of learners who ideally receive tailored support reflecting their needs.

The relevance of STEAM education for economic prosperity

Arguments for why STEM education is so important economically, are twofold. Firstly, STEM based jobs pay on average better and thus increase individual prosperity (see for instance, Lacey and Wright, 2009). Secondly, STEM jobs and related businesses are believed to increase the innovation potential of countries contributing to the overall GDP and thus to national prosperity. Studies have indicated that in Western countries not sufficient students are enrolled in STEM studies in order to fill the vacancies in STEM jobs (e.g. forecast for 2018 in President's Council of Advisors on Science and Technology, 2012). So, the widespread concern is that universities do not deliver sufficient graduates in STEM subjects to make the national economy prosper.

This focus on STEM subjects however has led to neglecting the importance of artistic and humanistic education (Aróstegui, 2019). Thus, as a result of increased efforts to engage students in STEM subjects, these have received extensive STEM training at the "expense of other unique human facets, especially the artistic, with consequent repercussions on students' learning in terms of subtracting them from a holistic view of the world" (Perales & Aróstegui, 2021, p.2). STEAM education could be defined as an interdisciplinary and transdisciplinary approach equipping people with a more holistic view of the world, building on convergent and divergent thinking skills (Land, 2013). There are increasing voices counteracting the discussion on the economic relevance of STEM education (Giammarco, 2020; Perales & Aróstegui, 2021) arguing that the future of learning and work in a fast-changing world demanding human rather than technical skills such as social and emotional intelligence, creativity, intercultural competences, etc.

Although the decision for a (STEM) career path seems individual and voluntary, there are structural factors influencing these choices (Niu, 2017). The discussion focuses mostly on formal degrees although of course science learning does not only take place in schools, nor does it always end in a formal qualification. Thus, government policies tend to focus on opportunities to remove barriers to participation in STEM subjects in educational institutions (Gorard & See, 2009).

Barriers are to be found on different levels, from individual dispositions to the intuitional and larger societal barriers. While not making the claim to be able to provide an exhaustive analysis, a few of these barriers will be explored in this report.

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The EU has identified 7 priority challenges[1] where targeted investment in research and innovation can have a real impact benefitting the citizen:

- Health, demographic change and wellbeing
- Food security, sustainable agriculture and forestry, marine and maritime and inland water research and the bioeconomy
- Secure, clean and efficient energy
- Smart, green and integrated transport
- Climate action, environment, resource efficiency and raw materials
- Europe in a changing world - inclusive, innovative and reflective societies
- Secure societies - protecting freedom and security of Europe and its citizens.

Socio-economic family conditions impacting on STEAM participation

While it is difficult to single out the socio-economic status of families in relation to STEM participation as many different barriers play out at the same time leading to intersectional effects, we place the focus here on challenging conditions at the family level. The family is the first primary socialisation environment for everyone shaping trajectories in life with family supported skills, shared values, norms, and traditions (Archer et al., 2012). The families' socio-economic status as a result of the educational background of parents, their occupation and financial wellbeing is a stratifying factor in participation and accomplishment in formal education and participation in informal education as many studies show (Seebacher et al., 2021). The socio-economic background further correlates with factors such as ethnicity, family structures, language at home, and urbanicity (Votruba-Drzal et al., 2016).

Following the argument that the educational system does not prepare sufficient graduates for STEM job vacancies to be filled on the one hand, and that STEM careers do often correlate with higher income on the other hand, it is in fact concerning that students from less privileged backgrounds are underrepresented in the STEM field. It constitutes a missed chance for the society at large if some of the talents are missed out. In fact, economically less-privileged students would benefit from a STEM career but tend to experience less success in school, and leave tertiary education without a degree (Niu, 2017).

These negative effects play out early on. Socio-economic disparities in STEM achievement are to be found already at elementary school level (Betancur et al., 2018). Once young people reach high school and make their decisions regarding their future educational and career path, it might be too late to close these disparities and the real available choices are then more limited than they could have been (Niu, 2017) if students were better prepared for upper secondary and tertiary education. As the family income (and parent's education) correlates highly with grades in mathematics as well as reading skills, elementary instructional approaches would have to reflect science instruction with reading and maths

[1] https://www.ncpwallonie.be/en/project-horizon2020-challenges

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skills in order to enhance the overall performance. Thus, policies need to target children at this early age already to avoid achievement gaps that otherwise are reinforced at consecutive school levels.

Higher family income seemingly compensates for other negative predictors for STEM enrolment such as gender and ethnicity. For instance, migration background of students in STEM participation does not play a role among higher income households but does among lower income students leading to different decisions regarding STEM enrolment and STEM careers. Low-income students might lack the information and skills to come to a pondered decision with all potential opportunities (Niu, 2017). They are more concerned about the practical applicability of their degrees on the employment market than higher income students and they tend to make choices which reinforce their socio-economic situation (ibid). The direct (such as university fees) and indirect costs (such as transport, childcare support, and foregone income) of continuing with tertiary education add up questioning the affordability of education and affecting them disproportionally (Gorard & See, 2009). While some continue education to earn more, for others staying in education constitutes a poor alternative to earn money.

McDool and Morris (2020) argue that lower socio-economic status might lead to more rejection experiences at school and create anxiety in assessment and evaluation situations, which can burden the cognitive capacity during exams (Beilock et al., 2017). Studies indicate that these experiences correlate with greater difficulty in regulating negative emotions and with worse academic performance (Rheinschmidt & Mendoza-Denton, 2014).

Thus, there are different aspects and manifesting impacts to consider when it comes to socio-economic disparities of school children.

Science resources in families

The educational background of parents plays a role in different ways. International tests such as TIMSS have revealed a consistent pattern of home backgrounds correlating with pre-16 achievements in science across the globe. Students from families with higher socio-economic status, with modern equipment and more books outperformed others (Mwetulundila, 2000).

Parents with higher educational degrees often have more elaborated skills in relation to STEM subjects to support their children in their homework which might in turn increase STEM participation and accomplishment (Gorard & See, 2009). Their involvement might also include participation in school events or discussions with their children after school. Available resources for supporting learners such as investing their own time but also financing private tutoring correlates again with the socio-economic background of families (Jordan, 2010).

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Parents with higher education might be more likely to provide an environment in their homes that is more conducive for educational attainment and science interests and offer also more opportunities for out-side of school science activities. Studies suggest that parental education is at least as important a factor as socio-economic background (which is of course also correlated). According to a study by Betancur et al. (2018), it is through mathematics, and reading achievement that parental education and family income materialises explaining moderate gaps in science achievement. Higher levels of parental education predict significant increases in science achievement. These effects are visible early on, from 3rd grade and remain large through 5th and 8th grade. This was found also in earlier studies (cf. Gorard & See, 2009) which detected those characteristics as influential on later trajectories which are set early in an individual's life such as age, sex and family background with an accuracy of 75%.

There is also a strong correlation between parental attitudes towards science and youth interest in STEM (Falk et al., 2016), while no correlation was to be found between STEM interests and teacher variables in a study by Falk et al. (2016) indicating again that the outside-of-school environment heavily influences educational attainment. The educational capital and corresponding values and norms in families are well captured with the "family habitus" concept by Archer et al (2012) following the theory of cultural reproduction by Bourdieu (Bourdieu, 2001) including the family identity. This identity opens (or closes) different potential choices that are imaginable. For instance, children from working class families with a lower socio-economic and educational background do not perceive science as part of their identity and becoming a scientist as a viable choice. The family habitus thus contributes to the identity formation ('who we are') at the level of the learner's family setting. It further allows children grown up in families with higher education capital to adapt more easily to different educational settings (Goldthorpe, 2007). It is especially the mother's educational level influencing the learner's performance across all different subjects according to Gorard and See (2009). Particularly the child's early environment is impacted by maternal education, and with this it predicts the development of executive functions and language and lastly STEM achievement. The children's language and executive function in turn influence higher-order cognitive skills, such as reasoning (Blums et al., 2016).

A study by Seebacher (2021) with around 1,500 visitors of non-formal science education in different European countries and Israel revealed that it was primarily the educational capital (measured as index with highest level of education, parents' profession, and reading material at home) than gender aspect influencing whether science was perceived as an important part of the learners' home culture. These children are not necessarily less interested in science but rather experience a feeling of not belonging- 'science is not for me' (Seebacher et al., 2021).

A similar pattern is also found in extracurricular activities and participation in 'arts' hobbies such as playing an instrument c hildren from higher educated households were more likely

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to have musical instruments at home. While children from low educational groups who identified as male were least likely to engage in art-based science learning, female identified learners from higher educational households were most likely to participate (ibid). Gender differences thus intersect with socio-economic and educational differences. When it comes to informal science learning in extracurricular activities, it is mostly boys from highly educated households who participate in such.

Taking into account all the above study results, an open point of discussion is what schools can do after all if the trajectories are already set early on and are sharpened by many factors such as household income and educational background of parents which lie beyond the sphere of influence of schools. We cannot argue that teaching has to be more inclusive and tailored to the needs of very diverse children - diverse in many different ways challenging traditional pedagogical approaches. Teachers obviously play a crucial role. Diverse classrooms need teachers who are well equipped in serving different needs. However, a study by Betancur et al. (2018) shows that low-income children are likely to have inexperienced teachers. Schools in disadvantaged neighbourhoods tend to also have less-equipped teachers. Traditional classroom settings tend to favour learners from middle and upper-middle class families as confirmed by different studies (Bell et al., 2009; Kurth et al., 2002).

3.1.2. The need for a science literate European society and to encourage more interest in science for young & old

What is science literacy

The notion of science literacy goes far beyond scientific knowledge and the comprehension of basic scientific concepts. According to Zen (1990), science literacy involves the understanding that scientific theories and hypotheses are falsifiable, and that scientific inquiry is value-laden, as well as involving the understanding of the problem-solving nature of the scientific inquiry. The Organization for Economic and Community Development (OECD) prefers the use of the term “scientific literacy” over the term “science” for the purposes of the Programme for International Student Assessment (PISA) 2018, to emphasise the application of scientific knowledge in the context of real-world situations. In this context, OECD defines scientific literacy as “the ability to engage with science-related issues, and with the ideas of science, as a reflective citizen”. It is expected that a scientifically literate person will be willing to engage in reasoned discourse about science and technology requiring the competencies of explaining phenomena scientifically, evaluating and designing scientific enquiry, and interpreting data and evidence scientifically (OECD, 2019a).

Why science literacy is important

Science literacy is widely recognised as an important asset both for individuals as well as for communities, societies, and economies. NASEM (2016) identifies four broad rationales for

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the necessity of science literacy: the economic rationale, the personal rationale, the democratic rationale, and the cultural rationale.

The economic rationale considers science literacy as valuable in the context of advanced economies requiring a scientifically and technologically skilled population, because it strengthens economies and economic competitiveness, leading to less unemployment and a high standard of living. This rationale is closely related to the long-standing impetus for educating the general population in science and the argument that the knowledge capital of nations is "powerfully related to long-run growth rates" (Hanushek and Woessman, 2016).

The individual rationale focuses on the help science literacy may provide to people so that they can respond to issues and challenges emerging in their personal and community contexts. Thus, the understanding of, and ability to interact with, science may help people to make informed decisions, take actions and lead richer, healthier lives (OECD, 2013), e.g. in relation to their health, their consumption of materials and energy, or their lifestyle: "*Many conversations with health professionals require some understanding of the body, the structure and function of its many organs and systems, and even the nature of risk. Similarly, decisions and choices about energy may be informed by some understanding of the concept and the consequences of one choice in comparison with another.*" (NASEM, 2016). Similarly, Zen (1990) pointed out that science literate citizens can better cope with many of their problems and make intelligent and informed decisions positively affecting the quality of their lives. Further, to illustrate the importance of scientific literacy in adulthood when making crucial decisions, Ashbrook (2020) notes:

> "*As adults, before taking an over-the-counter medicine we need to decide if our symptoms will be helped by the medicine. To inform our decision, we consider the messaging on the product packaging, information from a doctor or pharmacist, and prior experience with using medication to reduce symptoms. We think about which sources of information are trusted sources because they had accurate information in previous experiences or are based on research. To know if we are taking the correct dosage we also need to know measurements: our age and weight, how long it's been since the last dose, and how to measure or count a dose. Every day adults make many informed decisions—such as whether to text while driving or have their children immunized—and evaluate explanations from others. Being scientifically literate helps us make decisions that are in our best interest.*"

Beyond the level of the individual or community, science literacy may hold significant value for societies and nations, providing a context for addressing societal problems. For example, Zen (1990) highlighted the pivotal role of earth-science literacy in addressing critical environmental problems such as the influence of explosive population growth on the consumption and depletion of natural resources and the avoidance of natural hazards. Further, it is argued that in a democratic society science literate citizens may help make prudent and equitable decisions on policy issues involving science (Rudolph and Horibe, 2015). Indeed, the democratic rationale for science literacy, according to NASEM (2016),

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refers to science literate citizens being informed participants in civic decision making on major problems facing humanity which should be understood and addressed, at least in part, through scientific and technological advances. Thus, by engaging, for example, in deliberation, persuasion, or the donation of time and money, members of the public may participate both in decisions about the use of scientific knowledge (e.g. on ways to minimise air pollution) and decisions about the allocation of resources to the production of scientific knowledge (e.g. on supporting funding of stem cell research) (Rudolph and Horibe, 2015; NASEM, 2016).

Nevertheless, NASEM (2016) notes that the available evidence does not provide enough information to draw conclusions on whether such claims about the democratic effect of science literacy are justified. It is also noted that it is important to consider different countries as different societies, characterised generally by different cultures, level of economic development, and form of governance, as well as considering the differences between a society and a community (NASEM, 2016).

From a different perspective, the cultural rationale for science literacy does not resort to any extrinsic or utilitarian justifications. Rather, science and technology are seen as important cultural activities significantly shaping our culture in modern Western societies, and therefore as an integral part of a person's liberal education (Bereiter, 2002). As Cossons (1993) puts it: "*In order to decode our culture and enrich our participation - this includes protest and rejection - an appreciation/understanding of science is desirable.*"

Finally, as a concern cutting across all of the four rationales presented above, it is important to acknowledge the role of science literacy in the current environment of rapidly developing technologies and society's expanding access to information. While media have traditionally been the main source of science information for lay audiences (Dudo et al., 2010), since the advent of the Internet, knowledge intermediaries between science and the public such as journalists and the press have increasingly lost their role as gatekeepers making judgments about scientific expertise and filtering questionable scientific ideas (Hargreaves and Ferguson, 2000). Increased access to information has shifted the predominant model of science learning from a need to store content information over time in one's mind, to a "just-in-time" model (Miller, 2010), whereby science related questions are answered immediately through online searches (Brossard and Scheufele, 2013). In addition to increased public access to trustworthy new science information such as peer-reviewed studies, the new media also offer ample access to information about scientists' disagreements, mistakes or fraud, as well as to misinformation through content supporting scientifically questionable views and lay audiences' inaccurate contributions in online environments to the body of available information about science (NASEM, 2016). For citizens to navigate in this landscape, it is necessary to be able to integrate and interpret information, as well as investing time and effort for reflection and evaluation (Crowell and Schunn, 2015).

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The need to increase science literacy

In this context, it becomes clear that citizens' science literacy, including those of the younger generations, is of paramount importance. Zen (1990) considers increasing the science literacy of the general public through interdisciplinary cooperation as an even more important priority than the recruitment of future scientists. Ashbrook (2020) points out the need for education to prepare children to make informed decisions and evaluate claims and explanations from others, as well as supporting their understanding of scientific knowledge. Vartiainen and Kumpulainen (2019) show how early science education that draws on multiliteracies pedagogy can provide children with rich opportunities to engage in operative, cultural and critical dimensions of scientific literacy embedded in children's life-worlds, understanding how they can actively participate in the existing scientific culture.

In the context of the challenges, change, uncertainty and complexity that characterise our era, current research on science education for citizenship frames the need for science literacy within the sustainable development competencies that school-leavers should possess in order to meet the challenges of the 21st century (Pellaud et al., 2021). Further, Tasquier et al. (2022) highlight the need for new forms of scientific literacy empowering students to gain agency over their learning processes and become agents of change. In this aspired new paradigm, school education equips young people with the scientific literacies required for tackling current societal challenges through transformation across practical, political, and personal spheres.

The role that education is required to play towards increasing scientific literacy is widely recognised in the European political context. Siarova, Sternadel and Szőnyi (2019), for example, highlight potential education policy responses to better prepare scientifically literate citizens empowered to navigate and critically address the vast amounts of information exchanged in public debate, in face of the emerging threats relating to the spread of disinformation and pseudo-science.

Finally, addressing the pressing need to increase scientific literacy should be seen as a shared responsibility. As Clough (2010) puts it:

> *"The times require all those whose efforts are needed to step forward and accept the responsibility to improve the level of scientific literacy. Families, scientists and engineers, professional organizations, universities, research organizations, and museums all have skin in the game and need to link arms to meet the challenge. All must aim their efforts at providing a rich array of formal and informal opportunities for citizens of all ages to improve their scientific literacy, and at greatly expanding opportunities for public discussion and debate about the future directions of science. Such discussions should bring together scientists and laypeople who have a vested interest in science, and should take place at all levels, from local science cafes to national summits. Finally, there has never been a greater need to seek common*

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ground with those who are doubtful about science. If we are to succeed in opening a dialog, we will need to speak with clarity about the uncertainty in science and about the potential negative consequences of scientific advances. We should also listen carefully to those outside the science enterprise and recognize that there is no monolithic viewpoint, but rather a full spectrum of views that should be included so that the issues are clearly stated and the causes are understood." (Clough, 2010)

3.1.3. The need for more highly educated scientists to increase the uptake of science careers

Back in 1992 Carl Sagan brilliantly challenged two important prejudices which besiege scientists that choose to communicate with the general public: the idea that scientists who do are distracted from their "real" work – research – and the idea that scientists are not able to express themselves clearly, as if their mental universe were so far from the common man that at the very least, they need a "translator".

Attitude towards science

For many years the S&T Eurobarometer surveys demonstrate that the situation has not changed significantly and results – among other relevant issues – have shown that the Europeans believe that "Because of their knowledge, scientists have a power that makes them dangerous". In many of these surveys (at least until 2015), about 62% of young Europeans (less than 25 years old) believed that Astrology is a highly scientific issue. These results should be considered as rather annoying, now that Europe has the major aim of becoming "the most competitive and dynamic knowledge-based economy in the world".

The main reason behind this attitude is the lack of attractiveness of science matters as well as the lack of relevance to everyday life. Much has been written about why young people do not find science studies appealing, and it is easy to criticise school science education. But a closer look shows that given the pervasive nature of science in our modern societies we cannot expect our formal education systems to carry this responsibility in isolation: science is simply too broad, and if we want to foster the emergence of a truly scientific culture, then other actors have to be involved, too.

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Interest in science

Surveys and studies show that young people are turning away from science studies at school although their general interest in science remains high. Innovative methods for creating a new type of interactive hands-on science education solutions are proven capable of reinforcing the teachers to increase students' knowledge of and interest in science but also to increase their intrinsic motivation to learn science at school; to help teachers develop key skills; and to develop a more inclusive approach in which the different needs of boys and girls are also taken into consideration.

The world has changed dramatically over the last hundred years (Ramakrishnan, 2017), has evolved and helped people's everyday life in many areas, with science and scientists making a decisive contribution to this change.

The recent experience of dealing with COVID-19 pandemic (c.f. section 3.1.6) has shown that a scientific way of thinking is necessary for all members of society and that it is the cooperation of scientists from different disciplines that can provide real solutions to urgent situations.

Science in times of complex challenges

This is necessary because apart from the contribution of science and the scientists that we mentioned about the COVID-19 pandemic, in the present time there are also important challenges that exist and can only be answered and addressed satisfactorily with the contribution of science and scientists. Rob W. van Leen, Chief Innovation Officer, Royal DSM, depicts that "just as science was the cornerstone of great advances of the past, so it will be fundamental to meeting the societal and environmental challenges of tomorrow".

So, apart from diseases becoming pandemics (a result of a globalised society with quick and easy travel), many more challenges await us, such as climate change, energy efficiency, food security, the use of Artificial Intelligence and many others.

Hence, we need as a global society, citizens who can understand basic scientific concepts, principles and operations, but we also need, inclusively, many more scientists, and professionals in fields of mathematics and engineering.

One way to achieve the above is through education, as one can easily understand. Consequently, it should on the one hand cultivate in all students - if possible - a scientific way of thinking and problem solving and on the other motivate them to pursue science, mathematics, and engineering as a career.

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But let's start with the very basics: how do students view scientists and science? Would they want to go into science, i.e. pursue such a career? Are there any obstacles that appear on the way to this option?

The image of science and scientists

Let's look at some evidence from the research that is relevant to the image and view that students have of science and scientists.

For many years now (almost forty), North American schools have given a short test called "draw a scientist"[2]. Essentially, this test is aimed at gathering students' perceptions of scientists, including their gender, characteristics, and working conditions. While it is a pleasant occasion for discussion, it also arouses interest in science, scientists, and a career as a scientist.

Reading the analysis and results from the systematic study by Miller and others (Miller et al., 2018) for the development of children's gender-science stereotypes, in which data on the implementation of “draw a scientist” are reported, we find some very interesting facts. First, that in these 40 years there has been a very slow (but) change in the stereotypical image of scientists that students have of scientists in terms of the gender of the scientist and some other key characteristics of his or her work. As highlighted in the article (Miller et al., 2018): «*Children’s depictions of scientists therefore have become more gender diverse over time, but children still associate science with men as they grow older. These results may reflect that children observe more male than female scientists in their environments, even though women’s representation in science has increased over time*».

In other words, depending on what they observe in their social environment (the social environment for students is basically: school, family, social media - which has become an important part of social life in recent years - television, movies), influences and shapes the students and shapes their opinions. Based on cognitive science about the concept of gender and beyond, evidence from the immediate social environment is sought to form opinions. A significant effect is thus found in addition to the increasing reflection of women scientists in the media and communication and the increase in the number of women scientists in schools.

Most of the students at the beginning and in a percentage of almost 100% in the first years of the survey (which decreased over the 40 years of the study) associate scientists with male scientists (c.f. section 3.1.5). Women are increasingly represented in the media and social networks as scientists, teachers, or as images in the media and social networks, so the association even though it was very-very strong it is progressively decreasing.

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[2] https://castle.eiu.edu/~scienced/329options/crbscience.html

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Furthermore, the same article (Miller et al., 2018) states that although "*Girls in recent years may now develop these interests more freely because these stereotypes of scientists have become more androgynous over time*", of particular importance is the extent to which this influences the decision or thoughts of becoming a scientist, as it is also emphasised that "*this limited view of scientists might have restricted children's science-related educational and career aspirations, to the extent that children did not identify with such depictions*".

At the same time, research of Makarova et al., (2019), which analysed how women's enrolment in science courses relates to the gender-science stereotype based on a survey of about 350,000 participants in 66 nations, concluded that explicit and implicit national gender-science stereotypes were weaker in countries with a higher female enrolment in tertiary science education.

OECD data show that female teachers are more likely to teach language and social science and less likely to teach maths and science. Girls therefore seem to lack science, maths , and engineering related role models in their school. Although in recent years (*average among OECD countries)* girls have even reached and surpassed boys in science proficiency are not chasing careers related to "engineering and computing" as reported in PISA article where "*fewer than 5% of girls, but 18% of boys, expected to be working in engineering and computing as young adults".*

There is not only gender discrimination, but also racial or economic discrimination, as well as mobility or other difficulties that exist in STEM careers. For instance, at the United States of America, African Americans, Latinos, and Native Americans are historically underrepresented minorities (URMs) among science, technology, engineering, and mathematics (STEM) degree earners (MacPhee et all., 2013) at the same time in UK (*British Science Association*, 2022) corresponding conclusions emerge regarding diversity in STEM professions.

The continued presence of stereotypes and exclusions will discourage students from studying science in the future and problems that are self-feeding over time (although generally there seems to have some general improvement).

Therefore, more women, minorities, etc. should be involved in science, technology and mathematics, both because in this way there are no divisions, stereotypes are abolished and prejudices are removed, but also because in this way more mathematical and engineering scientists will exist in the future capable of supporting the needs and solving the emerging problems of our planetary society.

To make this a reality it is important to come into contact with scientists, initially at younger school ages, but also during the school years, since it has been observed that students' interest in science decreases over the years at school, as Barmby et al (2008) mentioned, and to be motivated in this way to consider science as a possible career in the future. This

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contact with scientists and their way of working and their profession in general might give students the opportunity to see some kind of identification or motivation within a social context, that of the school to pursue a career as a scientist.

Projects like the CREATIONS (http://creations-project.eu/) and the Open School for Open Societies - OSOS (https://www.openschools.eu/) demonstrate the approaches to achieve significant results in motivating students to raise their interest in science as well as in many cases to follow science careers. CREATIONS project provides 107 demonstrators, activities which involve students, teachers and researchers and engage them in STEAM activities. OSOS provides more than 70 accelerators and projects that can accelerate the school as a unit and provide students with the needed tools. In both projects the results in students' motivation to be interested in scientific notions and science issues was raised significantly.

An interesting project for high school students is called "I am a scientist"[3] which aims at that exactly. As its vision is described: "*Not every student wants or needs to pursue a career in science, technology, engineering or mathematics (STEM). However - should they choose to - demographics, interests, personality, and socio-economic status should never get in their way. With "I Am A Scientist," we're building classroom tools to make STEAM careers technically and psychologically accessible to all students".* Twelve of the 22 scientists featured in the project, and they are getting in touch with students, are Harvard-trained or affiliated, so we can say they are highly educated scientists.

Since it seems (Blotnicky et al., 2018) that students in middle school have a limited STEM career knowledge around the occupations related to the content and activities of a scientist of STEM subjects and the same research also depicted that «*Exposure of students to STEM careers can enhance their interest in pursuing careers involving science, technology, engineering, and mathematics*». Initiatives of this kind are taking place in schools in Europe and all over the world and gradually start to give results.

Role models

Role models (Morgenroth, et all., 2015) even though it does not seem to be a panacea for the under-representation of stigmatised groups, but it seems "*that role models have great potential in making a difference on role aspirants' lives*". This process should be continuous and should not work piecemeal as there are no role models suitable for everyone and this process may not work with one or two implementations.

In parallel is well known and in "Rationale 23" OECD (PISA 2024 assessment analytical framework science strategic vision proposal) states that "*Science education is playing an increasingly important role in providing young people with the crucial thinking tools needed to navigate a non-stop world … but science, through its specific methods and culture, can equip*

[3] https://www.iamascientist.info/vision

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young people with the competencies needed to critically examine them and responsibly engage with what they offer".

To cultivate a scientific way of thinking and problem solving, students should be brought closer to authentic problems and solutions that will give them a reason to engage with their course actively and meaningfully as stated by Childs et al., (2015), and even engage with examples from everyday life and industry (Hofstein & Kesner, 2015) to get even closer to these kinds of applications and careers. This is also supported by the Euridice report[4] at chapter five about the meaning and motivation that students take when they deal with real problems in the subject of mathematics.

Therefore, based on the above, it is evident that it is necessary to emphasise science, mathematics, engineering, technology, and its applications during school in order to cultivate scientific thinking as well as support the (possible) involvement in science, mathematics, and engineering by implementing examples and experiences from the real world and allowing students to interact with representatives of these professions. Real representatives of all genders and ethnic backgrounds could act as role models for students without exclusion or prejudice.

3.1.4. The need from industries for STEM (and STEAM) education

The current exponential growth, integration, and advancement of technologies in areas such as Artificial Intelligence, biotechnology, nanotechnology, computer power and sophistication, and their effects, have been described in economic and business circles as the "Fourth Industrial Revolution". This revolution is expected to bring significant changes in our lives, in employment, society, the environment, and in education. Education curricula have to consider the changes in the skills required by the workforce.

"Technical" and "soft skills" needed

These changes, as suggested by Penprase (2018) are fourfold:

1. higher education needs to support the capabilities of students to adjust and work in rapidly emerging and evolving areas such as data science and genomics,
2. emphasis should be placed on computer science as a form of new literacy,
3. interdisciplinary fields should be integrated into the education curricula, beyond the teaching of "traditional" primary sciences such as biology and chemistry, which will allow for more specialised workforce capable to further advance the fields of science and technology, and
4. put an emphasis and foster intercultural and interpersonal skills, such as ethical thinking, intercultural awareness, critical thinking, creativity, and intercultural understanding. The

[4] https://eurydice.eacea.ec.europa.eu/publications/mathematics-and-science-learning-schools-2022

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> students, after their graduation, should be able to understand and consider the impact of the new technologies and the shifting economic powers on the human condition in our increasingly interconnected world; they should be able to respect human rights, make thoughtful and informed applications of the technologies, and create a culture where technologies advance "sustainably and ethically". And this point is where the role of Liberal Arts becomes even more imperative in this evolving industry landscape.

These points, regarding the importance of the content of the STEAM skills and of "soft skills", are also stressed in a European Commission (EC) report comparing the labour market needs with the tertiary education graduates' skills in Europe (European Commission. Joint Research Centre., 2020). Two of the issues identified in the report are a) the "quality" of the tertiary education graduates as it seems that the skills acquired through their academic studies do not quite match the expectations of the employers, and b) the importance of "soft skills" such as teamwork, work ethic, and communication skills, which often seem to be overlooked by education providers.

This interconnection of STEAM skills further emerged in the interviews by two experts (game developers) in the gaming industry in Malta, which is one of the highest growing industries in Malta that we consulted in the framework of this deliverable. The two experts stressed the need for a combination of STEAM skills in the field: for game developers it is essential that they have critical and reflective thinking skills, but also a good background of STEAM related skills such as arts, mathematics, physics, and engineering. Employees in this industry often need to exhibit Art related skills and have a technical background in order to transfer the visual, auditory, or narrative content into the game environment, and complete tasks such as rendering, animations, and 3D modelling. As stated in one of our interviews regarding the need for STEAM skills in the industry: "*Definitely, from our side, the game development industry, we do need people with STEAM capabilities. There are several facets in the game; there are visuals, there is story, there are game rules, there is programming, the artistic, the visual and the audio part of it. And all of them have to come together usually through programming.*"

It seems that if we want to focus and support STEAM skills in relation to the industry needs, STEAM skills have to be defined clearly and in depth, and specialised. The specific STEAM areas and EU Member States that require STEAM skills and specialised employees the most, have to be carefully considered.

Mismatches in the tertiary graduate labour market

The 2020 report by the EC (European Commission. Joint Research Centre., 2020), which compared the demand and supply among higher education graduates in the EU and the needs of the industry and labour market, identified mismatches in the tertiary graduate labour market. Although there is a large pool of highly educated individuals unable to find a job, a large number of companies have problems finding the appropriate employees for filling their

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vacancies. Although the report predicts a small excess of graduates in ICT and Science and Engineering at the EU level by 2030, the results differ greatly among Member States. Countries such as Czechia are expected to have a shortage of graduates in ICT and Science and Engineering, while in countries such as Ireland and Germany, the exact opposite is expected (i.e., surplus of graduates).

The increase of skilled labour in the ICT sector constitutes one of the needs and objectives of the "Digital Decade" programme in Europe. One of the targets is to reach 20 million employed ICT specialists in ICT by 2030. To this end, education plays an important role, supported by initiatives such as the 2021-27 "Digital Education Action Plan" and the Erasmus+ programme (European Commission. Directorate General for Education, Youth, Sport and Culture., 2022, p. 43). The need for digital skills is further stressed in the European Commission's "2030 Digital Compass" where it is stated that more than 70% of businesses report a lack of staff with adequate digital skills as an obstacle to investment (*Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions 2030 Digital Compass*, 2021).

One of the main issues regarding STEM skills in the workforce are the strong gender disparities across fields of study, which are later detected in the workforce gender representation. As discussed in the "Education and Training Monitor 2022 - Comparative report" by the EC (2022, p. 41) *"Men are underrepresented in the fields of education (21.5%); health and welfare (28.1%); arts and humanities (35.5%); and social sciences, journalism and information (35.6%)"* while in STEM disciplines "*women only represent 31.3% of the enrolled students despite good employment opportunities in this area*". Some of the determinants of this gender gap, as identified in the same report, are the educational context, the structure of the labour market, cultural values, and social norms (c.f. section 3.1.5). The acquisition (or lack) of STEM skills further has a direct impact on the entrepreneurship ecosystem; representation of women in entrepreneurial sectors such as advanced technologies and STEM is very limited. A 2018 report shows that only 16% of global technology companies had a female founder (Brush et al., 2019). Women are less likely to pursue business ownership in sectors such as STEM industries when they have not had the opportunity to develop relevant skills and competences. Closing this gender gap is critical for higher productivity, increased labour market activity, and economic growth (European Commission. Directorate General for Education, Youth, Sport and Culture., 2022, p. 43).

It is evident that STEAM skills are crucial for the workforce and the industry, but beyond that, certain aspects have to be carefully considered when examining the STEAM education practices, such as the careful and detailed identification of the specific STEAM skills and directions supported, the degree to which these skills are holistically and interdisciplinary supported and promoted, the digital skills and digital literacy permeating these skills, representation and access to these practices and skills by all genders, ethnicities, and minorities, and the support of interpersonal skills, creativity, innovation, and critical thinking.

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3.1.5. The need for widened sociocultural participation and deconstruction of STEAM stereotypes

The under-representation of women, ethnic minorities, those from low socioeconomic backgrounds and other marginalised groups in STEAM fields continues to be a problem throughout Europe and beyond (Amo et al., 2021, October 26–29; Hazelkorn et al., 2015; Villanueva Baselga et al., 2020). This lack of diversity is seen as a major obstacle to the region's economic competitiveness and prosperity (European Committee of the Regions, 2019, June 26–27). Meanwhile, increasing the diversity of those working in STEM fields has been shown to improve the quality of research and its societal relevance (OECD, 2018). This section summarises the issues around Equity, Diversity and Inclusion (ED&I) in STEM and discusses the evidence of how STEAM approaches are suggested to address some of these issues (snapshot with examples highlighting inequality in STEM). For an overview of gender gaps in STEM engagement see Figure 1.

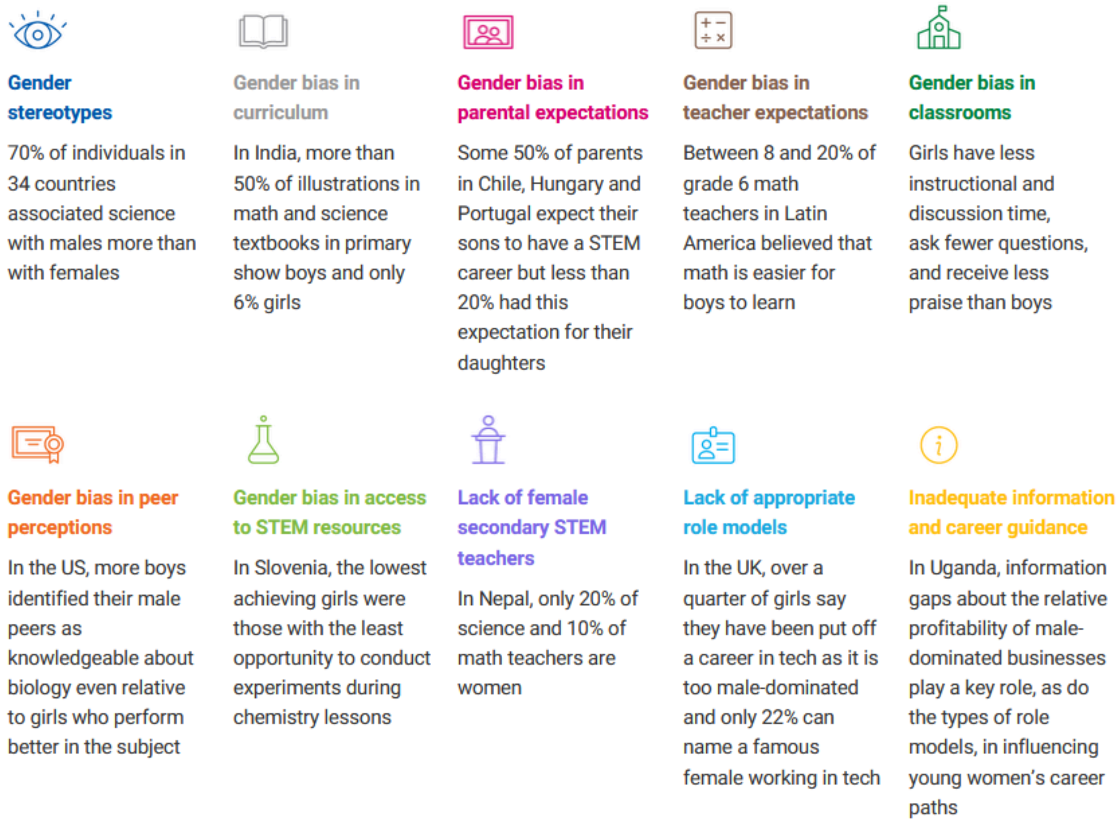

Figure 1: Mapping STEM inequality. Gender gaps in STEM engagement, interest, enjoyment, and future career aspirations are shaped by gender norms, bias and stereotypes[5]

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[5] Source: https://www.unicef.org/globalinsight/stories/mapping-gender-equality-stem-school-work

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Moving from the 'leaky pipeline' to 'hostile obstacle course'

A common element of the diversity in STEM discourse is the metaphor of the 'leaky pipeline'. This metaphor explains the problem as high-achieving, trained individuals (usually women, but also from other underrepresented backgrounds) leaving STEM fields at different education and career stages (Clark Blickenstaff, 2006). One of the biggest 'leaks' is located in the transition between secondary education and tertiary education, as students from underrepresented backgrounds are more likely to choose non-STEM programmes or opt out of Higher Education completely (Flynn, 2016; Holmegaard, 2015; Smith, 2011).

A major criticism of the pipeline metaphor is the implication that the solution is to simply 'plug' standalone problems such as lack of role models, poor aspirations, etc. It is argued that this shifts the focus away from wider institutional and sociocultural factors which may have a greater impact (Ametller & Ryder, 2015). For example, the issue of stereotypes in STEM goes beyond a perception of 'nerdy', 'crazy-haired', 'old' men (Ruiz-Mallén et al., 2018). Those from underrepresented groups in STEM fields often encounter negative stereotypes about people who share their sociocultural background. For example, those from African or African-Caribbean heritage can be negatively stereotyped, (Asamani et al., 2022) while females can be characterised as having a lower ability than males in areas such as mathematics and reasoning (Smeding, 2012). These attributes are considered in opposition to those needed to be successful in STEM and can lead to a phenomenon known as 'stereotype threat', where apprehension about a negative stereotype someone feels associated with can negatively affect their academic achievement – which in turn reproduces those stereotypes (Spencer et al., 1999).

These issues, along with evidence of underrepresented groups being subjected to abuse and discrimination in STEM fields and recognition of the structural inequalities facing these groups (McGee & Bentley, 2017; Paganini et al., 2021), have led to a suggestion we should abandon the leaky pipeline metaphor and replace it with that of a 'hostile obstacle course' (Berhe et al., 2021). In doing so, the discourse around improving diversity in STEM fields shifts from one of 'improved participation' to that of social and epistemic justice (Intemann, 2009).

Ireland has conducted a massive literature review on barriers and effective interventions addressing gender balance in STEM. Over 900 relevant articles have been identified. In reviewing this large pool of knowledge, the researchers did not identify a single determinant barrier, as the overriding factor in achieving gender equity in STEM education. Concerning study and career choices by female students, they pointed to a move from psychological explanations to socialisation processes (family, the school, and the wider society).

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Here is what the review is recommending as actions to achieve greater gender balance in STEM:

- Improving interest, engagement, motivation, enjoyment, and self-perceptions of learners of all ages, while addressing negative stereotypes and building productive STEM identities.
- Strategies need to be developed and delivered at three intersecting levels, from early childhood to primary and post-primary education, rather than as isolated interventions:
  - Family: parent/guardian beliefs, attitudes, knowledge, encouragement
  - School and early years education: teacher and early years practitioner beliefs, enthusiasm, knowledge, encouragement via appropriate interactions with learners; gender-inclusive curriculum and learning environment
  - Society: communication of gender-inclusive social and cultural norms; promotion of approachable role models for girls and boys from various cultural and marginalised groups

Opportunities from STEAM for improving diversity

STEAM (Science, Technology, Engineering, Arts and Mathematics) approaches are often presented as a method for improving the representation of historically excluded groups in STEM, although the reasons behind this are not always explained (Maier-Zucchino, 2021). As such, STEAM initiatives have made claims that their approaches are inclusive because they utilise interdisciplinary and transdisciplinary working, or that STEAM makes more ‘contextualised’ learning experiences which can connect education to the ‘real-world’ (e.g., Marcus, 2017). Anecdotal evidence from university course leaders suggests that undergraduate courses which take a STEAM approach are more likely to attract students from underrepresented backgrounds than traditional STEM programmes (Leslie, 2020), and STEAM approaches address the issue of a perception by girls and certain ethnic minorities that STEM subjects are too hard so opt for Arts subjects instead (González, 2021).

Inclusion in STEAM is often presumed, but the mechanisms underlying it are not always made explicit. This makes it more difficult for those developing STEAM programmes to understand how to ensure they are optimising the opportunities available to diversify STEM. The following sections outline and discuss some of the evidence available. Many of these studies consist of evaluations conducted by organisers of STEAM initiatives or are the product of student dissertations/doctoral theses. There have yet to be systematic analyses of the veracity of the claims made. Nevertheless, they give some indication as to the opportunities afforded by STEAM to improve equity, diversity and inclusion.

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Student achievement, science/STEM interest and aspirations

Several studies have highlighted the relationship between STEAM and student achievement, with one study claiming a significant positive relationship between substantial arts integrated instruction and primary-school aged student achievement in reading and mathematics, particularly for disadvantaged learners such as those from low-income households, certain ethnic minorities and those with special educational needs (Ingram & Riedel, 2003). This finding was echoed by another study which reported that for women, ethnic minorities, and those from low socio-economic status backgrounds, taking fine arts as well as maths and science subjects at high school was positively associated with higher achievement levels than students (including those from dominant groups) who only took maths and science subjects (Rabalais, 2014). Even more compelling, a report by Catterall et al. (2012) analysed secondary data on students' study patterns from four large national databases and concluded that for socioeconomically disadvantaged children and teenagers, those who had high levels of arts engagement showed more positive educational outcomes across a range of areas than those peers who had low levels of art engagement. Prior attainment is often considered as a predictor for ongoing STEM participation (Gorard & See, 2009). Therefore this is a key element of the argument for utilising STEAM approaches with students from underrepresented backgrounds.

STEAM approaches have been reported to improve marginalised students' STEM content knowledge and STEM-relevant skills such as spatial awareness, coding, and prototyping (Anderson, 2015; Das, 2020, June 22-26; Deloitte Consulting LLC, 2018). As has been noted in the wider literature, girls and other underrepresented groups are less likely to be given opportunities to access enrichment activities developing STEM skills at an early age (Archer et al., 2012; Reilly et al., 2017). STEAM initiatives provide the possibility of remedying this unequal access.

Beyond achievement-related factors, STEAM has been said to improve interest, cognition and confidence in STEM for underrepresented groups, especially female students (Boone et al., 2020, 29 October - 01 November; Walan, 2019). In their STEAM intervention, Ruiz-Mallén et al. (2018) found that theatrical approaches to STEM provided their students with 'physical vocabularies of movement' and an 'aesthetic engagement' with science (p.771). They claim that this embodiment can produce an emotional response to science which, in turn, positively influences students' interest and motivation toward the subject. Furthermore, several studies have shown that STEAM interventions can improve awareness of the range of STEM careers and career pathways for female students and other underrepresented groups, with the potential to raise their aspirations to continue participation in this area (Deloitte Consulting LLC, 2018; Ng & Fergusson, 2020).

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Deconstructing STEM stereotypes and broadening STEM culture

One of the most exciting possibilities of addressing equitable participation in STEM is evidence that STEAM can deconstruct fixed ideas about who can be successful in those fields. Some studies suggest that STEAM can challenge perceptions that STEM subjects are too 'difficult' or 'technical', and therefore inaccessible (Aurava & Meriläinen, 2021; Ng & Fergusson, 2020). One possible reason for this is because the inclusion of 'Art' highlights the links between creativity, science, and inquiry (Perez-Felkner, 2018). Evidence to support this can be found in a study looking at aspirations to study computer science over 4 decades, which involved capturing respondents' artistic orientation (Sax et al., 2016). Early data showed that women with a strong artistic orientation were deterred from computer science (no such relationship occurred for men), but this relationship became weaker over time. The authors argued this new pattern may be due to the increased focus on the applicability of a computer science degree in various arts fields (Sax et al., 2016).

STEAM initiatives can also bring renewed emphasis on the value of qualities such as collaboration, creativity, and empathy (Niles et al., 2020). Indeed, it is the capacity of arts-based STEM activities to foster emotional engagement, Villanueva Baselga et al. (2020) suggest, which enables it to deconstruct stereotypes related to science practice – although they make this claim based on a comparison between two different types of intervention which they themselves have run, rather than with any evidence. Creativity and design thinking skills are posited to be beneficial to STEM students in developing pluralistic models of thinking through design activities (Li et al., 2019). For instance, by utilizing and integrating convergent and divergent thinking, the STEAM approach deploys brain-compatible strategies to integrate the arts (Sousa & Pilecki, 2013). Schulze Heuling (2021) argues that students of STEAM conceive of themselves as 'science makers', reconfiguring science as an active endeavour, rather than merely theoretical or abstract. This suggests that the Arts in STEAM can be used to disrupt notions that science is 'not for me' (OSHub Consortium, 2020).

Villanueva Baselga et al. (2020) propose that STEAM has the potential to help students from underrepresented backgrounds develop new forms of social and cultural capital i.e., social links and cultural resources which will support them to succeed in STEM. Others argue that truly equitable STEAM *validates* underrepresented groups' non-dominant cultural capital (Maier-Zucchino, 2021). Electronic textiles, for example, have been shown to make technical domains more accessible to underrepresented students by creating a 'culturally hybrid construction kit' (Kafai et al., 2014 p.538). In their e-textiles intervention, Kafai et al. (2014) saw female students increased their confidence in doing circuitry and coding, while both male and female students developed a new appreciation of the expertise required for sewing crafts, traditionally considered an 'easy', 'soft', 'feminine' skill.

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These ideas point to the implication that arts subjects have more successfully undergone decolonising processes than STEM subjects, meaning they are more attractive to ethnic minorities (Anthony Ash II et al., 2021). Meanwhile, it is argued that STEM subjects typically omit discussions around culture and ideology (Anthony Ash II et al., 2021; Leslie, 2020). By integrating arts in STEM, STEAM can create ‘culturally situated design’ and ‘culturally responsive/relevant learning’ (Gaskins, 2014), but only if STEAM approaches draw on a range of cultural contexts, languages, and knowledge (Babaci-Wilhite, 2020). This can avoid the criticism of some STEAM approaches for drawing on specific forms of art which *still* do not reflect the culture and heritage of those from underrepresented backgrounds (Bennett, 2016).

STEAM – an inclusive virtuous cycle?

The previous sections have discussed some aspects of STEAM with regard to its effectiveness in encouraging more girls, ethnic minorities and other marginalised groups for continuing in STEM fields. There is also evidence to suggest that STEAM initiatives can produce inclusivity because STEAM *appears* to be designed to be so. Several writers in this field claim that STEAM identities are generally more inclusive than STEM identities (Allen-Handy et al., 2021; DesPortes et al., 2016, March 02-05). Projects taking a STEAM approach tend to be made up of more diverse teams (Saint-Denis, 2021), and STEAM environments are seen by female students as a safe place to take risks in innovation, etc. (Huang, 2021). Additionally, they are less likely to be ‘bossed around’ by boys (Ng & Fergusson, 2020) and more likely to assume a leadership role (Peppler, 2013). Furthermore, the introduction of artistic content into STEM can diversify epistemologies in those fields, allowing those working in STEM to better understand and work towards issues of social justice (Niles et al., 2020). This could lead to a virtuous cycle of equity, diversity, and inclusion for the ‘makers’ of science and for those who are its’ subjects.

It is important to note, however, that inclusivity in STEAM shouldn’t be taken for granted or assumed. In formal education, the arts, and their associated skills, are often perceived as a luxury for the privileged few (Skowronek et al., 2022). Furthermore, females – especially those from ethnic minority or low socio-economic backgrounds – have been historically underestimated in their capacity for creativity (Reis, 2002). Areljung and Günther-Hanssen (2021) argue that gender-blind discourses in STEAM obscure how arts can be just as excluding as STEM. Similarly, Niles et al. (2020) point out that focussing on the values of collaboration and empathy may still have a limited impact on improving equitable experiences in STEM education. There is a tendency in the literature to conflate the use of inclusive pedagogies (e.g., project-based learning and open schooling in Alexopoulos et al., 2021; Ng & Fergusson, 2020), *in* STEAM approaches with STE**A**M itself being the driver for inclusion; more investigation is required to better understand the nature of the latter.

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Nevertheless, there is sufficient evidence to suggest that, when the Arts are equal to (rather than serving) STEM, STEAM as a movement has the potential to challenge historical, exclusionary epistemic boundaries in STEM by elevating new methods of meaning-making and giving recognition to a more diverse range of science/STEM/STEAM makers (Mejias et al., 2021).

3.1.6. The need to draw the right lessons from the COVID-19 pandemic

The value of hands-on and inquiry-based and problem-based approaches in the teaching of STEM (and STEAM) has been widely recognised. Despite the variety of available pedagogies and teaching approaches that are presented as good alternatives to traditional instructional models, there seems to be a consensus on the idea that pupils are more motivated and learn better in settings that encourage trial and discovery, experiments and various hands-on activities. There might be evidence that such approaches may affect the choice that pupils make concerning future careers.

The Covid19 pandemic extensively disrupted schools around the world. STEM classrooms that rely heavily on working with labs with hands-on activities for students were particularly hit.

A number of issues have been raised in various studies on the effects of the COVID-19 pandemic, though further work and particular attention to STEM and STEAM is needed:

- The emphasis that educational systems and stakeholders should put in the facilitation of schools opening up to their immediate and other communities through meaningful synergies with various actors.
- The support of digital readiness and school resilience in the face of major challenges, such as the current pandemic, by employing the use of digital technologies, appropriately framed to facilitate creativity-enhanced inquiry-based science teaching and learning.
- Programmes and classroom instruction for effective online delivery with identifying and adapting to the range of technologies available to support virtual teaching in differing schools.
- The increased familiarity by all partners with virtual formats has opened the door to greater participation by students in STEAM programs, online partnerships with STEM professionals and mentoring opportunities.
- STEAM resources that relate to the digital habits, needs and interests of the generation Z of school learners must be considered. Online engagement of pupils is not an easy matter.
- Supporting teacher digital leadership and resilience is a key requirement for the effective engagement of students with contemporary science, the wonder of scientific discovery and the merits of technological innovation at a crucial stage in their lives before their attitudes to science become negatively fixed.

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Further lessons include:

- Addressing inequities in students' access to technology, but also tackling systemic inequality affecting all aspects of education
- Student well-being is as important as digital readiness and curriculum reform
- Outdoor education and exploration in/of local settings may significantly enhance learning through physical movement and fresh air at a time when students have been more isolated at home than ever
- The pandemic had a more negative impact on girls than boys across the world
- In person schooling cannot be substituted by going fully remotely
- Peer-to-peer support and Continuing Professional Development (CPD) is extremely important for teachers

3.1.7. Interconnections between needs and EU policy areas

In 1993, the European Union (EU) was formed by European countries (European Union, 2022) to oversee economic and political integration in Europe to facilitate economic growth and provide military security. Although the European Union started mainly as an economic community, nowadays it not only wants to ensure peace within its borders but also protect its values and ensure the well-being and interests of its citizens (European Parliament, 2022). To prevent internal disagreements, the EU Member States have authorised the European Union to act via EU treaties in specific areas (European Commission, 2022) to pass laws. In the Council of the European Union, the EU Member States work together in different policy areas (Government Offices of Sweden, 2022) such as:

- Agriculture, fisheries, and food
- Competitiveness issues
- Economic and financial affairs
- Education and training, young people, culture, and sport
- Employment, social policy, health, and medical care
- EU relations with the rest of the world
- Environment
- General affairs
- Justice and home affairs
- Transport, telecommunications, and energy

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Looking at the needs described above, the areas regarding 'education and training, young people, culture and sport' and 'employment, social policy, health and medical care' are related to the Road-STEAMer objectives. Education and employment policy strategies are important for the European Union to avoid economic recession and increased unemployment in Europe. The European Union has to invest in education, training and research to help unemployed citizens find a job and maintain the professional skills of employees. A pension system and laws for workers' rights strengthen the social security system and prevent citizens from poverty and social exclusion. As mentioned before, STEAM education helps not only citizens to become critical beings, but also stimulates their creative thinking, and strengthens their innovation skills and collaboration competences through project-based learning. Curriculums have to be modernised according to the new requirements of the ever-changing working environment.

In 2017, an independent expert group on the Economic and Societal Impact of Research (ESIR) reflected together on the economic rationale for a new mission-oriented research and innovation policy and created an ESIR memorandum "*Towards a Mission-Oriented Research and Innovation Policy in the European Union*" (Georghiou, 2018). For Europe's 2030 strategy, research and innovation are fundamental pillars to achieve inclusive and sustainable growth in our modern society.

According to the expert team (Georghiou, 2018, p. 5-8), economic growth couldn't be measured only in quantitative terms, but also in qualitative terms by being research- and innovation-based, inclusive and sustainable. There is a need for a more holistic approach for future R&D and innovation policies by looking at the whole innovation cycle from the investment to the creation of new ideas, the implementation as well as the innovation and their diffusion.

Education, skills, and training are an important key for productivity enhancement and need horizontal policies to ensure the desired impact of the new mission-oriented policy (MOP) framework. A separation between 'science for science', 'science for industry' and 'science for society' is insufficient to understand innovation within the MOP framework. Innovation should be understood as an innovative non-linear process that requires interaction and dialogue between the involved actors on various points of the chain (Georghiou, 2018, p. 20).

In recent years, education in science, technology, engineering, and mathematics (STEM) has increasingly captured the attention of policy makers, who intend to prepare learners for the future demanding and evolving labour market. According to the Institute for the Future, by 2030 around 85 percent of the jobs haven't been invented yet and therefore need a creative, adaptive, and innovative labour force to face future challenges (Dell'Erba, 2019).

By including 'arts' to STEM learning, learning programmes could be enhanced and enabled learners to train their creative abilities by having access to STEAM education, which integrates 'arts' as an instructional approach for experiential and inquiry-based learning.

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STEAM education encourages learners to ask questions, experiment, improvise, work on innovative solutions to ‘real-world’ problems and gain experiences in the process of learning. Research results have shown that learners with STEAM learning experiences have higher achievements and enjoyment in learning than their peers (Graham & Brouillette, 2016). For better support and integration of STEAM practices in the educational landscape, Dell’Erba proposes three policy components as follows: (1) access to school certificates or diplomas; (2) funding on regional and national/international level; (3) ‘statewide’ coordination through leadership and guidance (2019).

3.2 Workshop results

ZSI organised an online co-creation workshop jointly with UoE for task 4.1 on the 19th of January. The workshop with consortium members covering different stakeholder groups and expertise was planned for two hours and took place in Zoom making use of additional online workshop tools such as Miro, Mural, and Mentimeter.
The agenda was as follows.

1. Icebreaker and introduction to the workshop
2. Dialogue around core questions of Task 2.1
3. Dialogue around core questions of Task 4.1
4. Mentimeter and criteria application modelling
5. Wrap up

In the second part of the workshop, dedicated to the report at hand, we worked with a mind map in Miro representing key findings of our desk research on socio-economic contexts and needs for STEAM (cf. Figure 2).

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Figure 2: Overview of findings from desktop research

The participants were split into two groups. Each group was briefly introduced to the respective findings and then asked for complementation and validation in the beginning by writing down their thoughts on sticky notes individually and then discussing them in the plenary. Towards the end of the discussion, we jointly formulated recommendations, which are described in the report's conclusions.

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Figure 3: Group 1 findings: STEAM economic relevance, disparities in STEAM participation and need for widened sociocultural participation.

The following issues and important discussion points were added by the group in relation to *economic prosperity*:

- Individual and collective prosperity is strongly connected to graduates' skills and spheres of knowledge. In order for companies to grow, skilled workers are needed (see discussion in group 2).
- Knowledge in/of the different disciplines is still important and better interaction between these is necessary also in terms of the relation to economy.
- A study in NL shows a significantly higher starting salary for VET education holders than for a diploma. According to a US study, these do also have higher well-being levels.
- Foster innovation with interdisciplinary education (teaching arts with/for science, not as separate subjects)
- Education to foster entrepreneurship and self-employment would further contribute to economic prosperity

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The following points were discussed in relation to *disparities in STEAM participation and achievement*:

- Disparities manifest early in education. There is a lack of support for those trying to catch up. Preschool and primary school teachers have to be trained in order to have a range of methods to teach STEM, from fun approaches to more traditional forms of teaching. Being good at STEM and being good at other subjects, e.g., arts and sports, are not seen as compatible. Meanwhile in schools, it is generally accepted to have low performance in STEM, it is however not so accepted in humanities subjects.
- There are great national differences in the education systems. In some countries educational choices have to be taken very early. In Greece for instance, arts is not taught after the age of 15, in other countries STEM subjects can be replaced by others at different degrees.
- Intersectional factors have an impact on STEM participation and achievement. Females and males have different skill: this should not be ignored but acknowledget to support girls in STEAM; Special Educational Needs such as neurodiversity (i.e., Asperger and sensory sensitivity) have to be taken into account, when designing STEAM approaches. Parents influence their children's educational and career choices. It is not only the bad experiences of children themselves but their parents' negative experiences influencing their children's STEM performance (EU project finding).

The following points were added by the group in relation to the *need for widened sociocultural participation and deconstruction of STEAM stereotypes*:

- Diversity with respect to both people and subjects have been shown to improve outcomes (e.g. company leadership, also in research projects).
- Diversity also creates positive examples for students, younger people or people about to change careers.
- Research (especially in medicine and AI) is dominated by data from Western/male subjects --> results are not transferable to other cultures
- Stop seeing the A on STEAM as "just" a complement or a tool. If it's seen as a real and important subject, it can be more powerful! It can help break down stereotypes (see the recommendations in the conclusions section).
- STEAM subjects relate to a better understanding of today's complex world and support informed citizens. When real problems are tackled, people feel more included and encouraged to participate in projects about real concerns.
- Holistic view of subjects is important.
- Open schooling as a way to increase interest and relevance.
- Role models and diverse educators are needed on every level. Highly successful role models might not be relatable, thus a variety of role models is crucial.

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- A lot of the work on STEAM makes claims for benefits but little actual evidence to support these claims, this is needed (see recommendations).
- Many barriers are structural which are difficult to change, however, with designing policy they can be influenced (see recommendations).

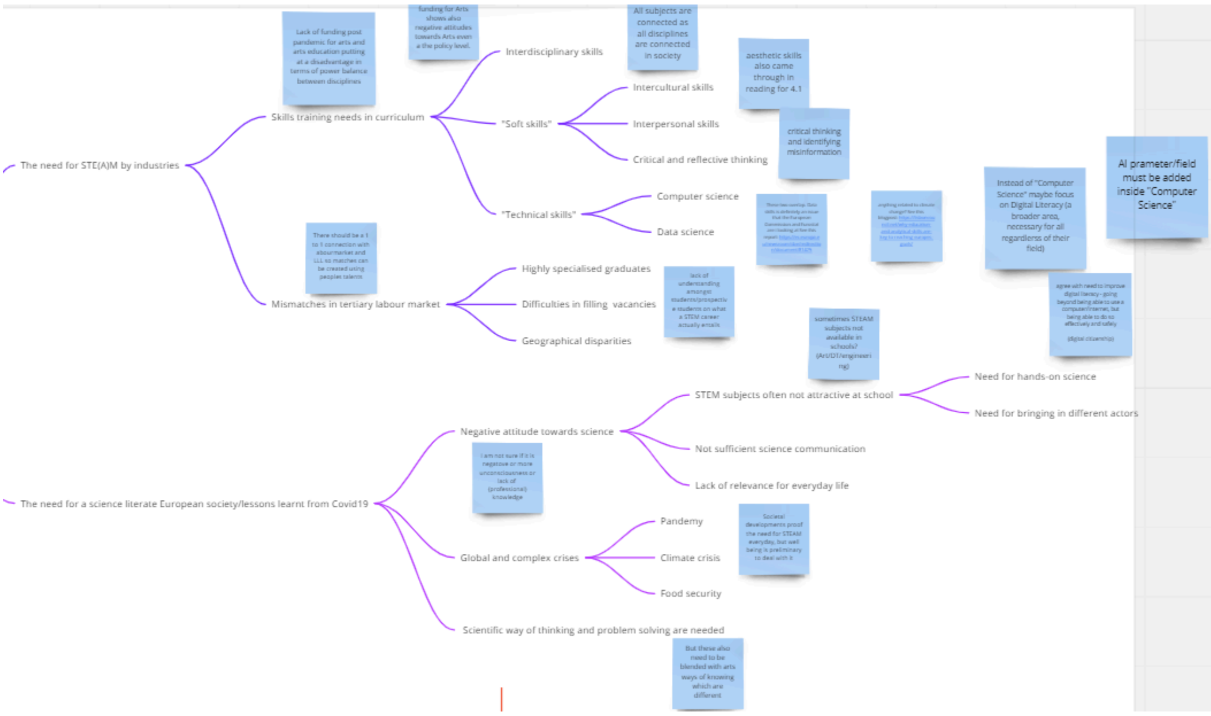

Figure 4: Group 2 findings: The needs from industry and the need for a science literate society

The following issues and important discussion points were added by the group in relation to the *need for STEAM by industries*, specifically with the focus on *skills training needs in curriculum*:

- Lack of funding post pandemic for arts and arts education putting at a disadvantage in terms of power balance between disciplines
- Lack of funding for arts also shows negative attitudes towards arts even at the policy level
- Emphasising interdisciplinary skills is important since all disciplines are also connected in society and in the ‘real world’
- Soft skills like critical thinking are crucial to identify misleading information
- Aesthetic skills are also important soft skills and are more elaborated in D4.1
- Technical skills like computer science and data science overlap. The European Commission and Eurostat are particularly interested in data skills as the following report shows: https://ec.europa.eu/newsroom/dae/redirection/document/81425

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- Instead of 'Computer Science', the Road-STEAMer project team should focus more on 'Digital Literacies', since a broader perspective is needed. It is not only important to be able to use a computer or the Internet, but also to know how to use it effectively and safely (digital citizenship)
- The 'Computer Science' field also includes the AI parameter/field

The following issues and important discussion points were added by the group in relation to the *need for STEAM by industries*, specifically with the focus on *mismatches in tertiary labour market*:

- There should be a better connection/communication between the needs of the labour market and the lifelong learning (LLL) trainings to match better the peoples' talents
- There is still a lack of understanding amongst students or prospective students on what a STEAM career actually entails

The following issues and important discussion points were added by the group in relation to the *need for a science literate European society* and the l*essons learnt from Covid19*:

- In some cases there is no 'negative' attitude towards science in general, but more a lack of professional knowledge or not being aware of science matters
- In some schools there are no STEAM subjects available
- Global and complex crises like the climate crisis needs to be more discussed (https://lisboncouncil.net/why-education-and-analytical-skills-are-key-to-reaching-europes-goals/)
- For the need for a scientific way of thinking and problem solving the aspect of 'Arts' should be integrated

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4. Results

Based on the desktop research findings which were complemented in the co-creation workshop, recommendations were formulated by the consortium members, concluding the report at hand.

In summary, the STEAM approach is promising and emerges as 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 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, more scientific studies are needed to test precisely which approach works better for whom and when. To provide a structured summary of the recommendations derived from the insights of this deliverable, we classify recommendations according to categories of key emerging societal needs and related benefits of the STEAM approach – and recommendations (Table 2).

Table 2: Structured summary of the recommendations based on Socio-economic context and relevant needs derived from the desk research and co-creation workshop

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.

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Societal needs	Barriers of STEM	Benefits of STEAM	Recommendations
2.Alignment of industry and societal needs with education	Provides only technical skills but organisations need skilled workers and 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, socio-economic, 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 organisational outcomes.	-Policy to affect structural changes (inclusion, access, diversity, i.e.: -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.
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.

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In the table, recommendations are listed according to categories with the purpose of providing a cognitively efficient summary. Yet, the reality is complex and multi-faceted: recommendations are related to more than one challenge and can often interact. For example, (diverse) science role models that are pioneers in research (the career element) and act as public figures (even as activists) within attempts to address certain societal challenges (the socio-economic element). It should also be acknowledged that solutions and recommendations are not free of barriers: role models can increase interest, but should not set the only standard, because that may lead to elitism or the feeling among young students that STEAM careers are only for the "brave". This can be addressed by focusing on another need, that of the student as a citizen scientist who through the work carried out in school, always in the context of STEAM becomes an active citizen acquiring and demonstrating the relevant skills and a level of scientific literacy that in principle would stick with him/her for life.

While developing the roadmap, the interactions (both positive and negative) between the recommendations and with societal need, should be analysed in a systemic manner.

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