Ref. Ares(2023)1467560 - 28/02/2023

Research Framework

Deliverable 4.1

Deliverable 4.1

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 1
Dissemination Level	Public
Project website address	

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Revision History

Revision	Date	Author	Organisation	Description
0.1	28.11.22	KC & LH	UoE	Initial draft
0.2	30.1.23	KC & LH	UoE	Second version
0.3	7.2.23	CA & SJ	Traces	Reviewers' comments
0.4	21.2.23	CM	Lisbon Council	Reviewers' comments
0.5	22.2.23	PK	EA	Reviewers' comments
0.6	24.2.23	LH	UoE	Revision, final formatting and pdf submission

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Abstract

This deliverable offers an initial outline of criteria the Road-STEAMer project will use to map and analyse STEAM practices in Europe. To achieve this, the project team used the participatory methodology at the heart of the Road-STEAMer project (see Deliverable 1.1). Both published literature and published projects were identified for inclusion in the analysis using a combination of literature searching and contributions from colleagues across the consortium. These were analysed thematically and categorised according to key areas of interest identified for the project to ensure relevance to the focus areas of open science-open schooling, the role of the Arts, the boundary between secondary and tertiary education, and the interaction with the real world. Following an initial in depth analysis, a co-creation workshop was held, which was used to refine and clarify the criteria to be used in the next steps of the project. Equity was identified as an underlying principle and value that supports all STEAM practice and is therefore an all-pervading criterion. The key criteria were identified as Collaboration, Disciplinary inter-relationships, Thinking-making-doing, Creativity, Real-world connection and Inclusion/Personalisation/Empowerment. The deliverable explains in detail how these criteria are reached, the published work on which they are based, and offers a description of each.

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1. Introduction

1.1 About Road-STEAMer

Road-STEAMer is a 3-year (September 2022 – August 2025) Coordination and Support Action (CSA) of the Horizon Europe Programme of the European Union (EU) (Project number: 101058405; Call Topic: HORIZON-WIDERA-2021-ERA-01-70). 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 bottom-up approach emphasizing educational practice and practitioners' agency rather than high-level conceptualizations of STEAM and generic top-down plans (in reality often just vague statements of intention) for its adoption in science education.

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

1.2 About this deliverable

Deliverable D4.1 'Research Framework' represents the first of three reports in Work package 4 (WP4) 'The landscape of STEAM practices' as an important means of defining boundaries within the Road-STEAMer project. While D4.1 focuses on defining the relevant body of data and the initial STEAM criteria, D4.2 undertakes a mapping of existing STEAM practices using the D4.1 criteria; D4.3 incorporates real-life use-cases via participatory action research; and D4.4 analyses and reframes the evaluation framework for STEAM practices to contribute to the STEAM Roadmap. The tasks and respective deliverables are cumulative, with outcomes relating to Work packages 2, 3, 5 and 6. All outputs are complemented with the contributions of the stakeholder groups (WP1).

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2. State of the Art

STEAM initiatives and actions are in place in all Member States. However, the approaches adopted are fragmented and the quality of provision is unevenly developed. To address this we are proposing a sustainable ecosystem approach to the Roadmap. This approach aims to capture the needs, contributions and relationships of all education-related actors and elements towards a holistic, sustainable ecosystem of organizational learning and promotion of STEAM-related innovations. As a consortium we are building on arguments that STEM in combination with the Arts has the potential to provide the framework for a wider engagement with science. We argue that STEAM could increase students' engagement, reintroducing creativity through art, and also catalysing the creativity perhaps lying latent within the sciences. We also argue that STEM curricula may benefit from the integration of arts and creative aspects to encourage creative solutions, not only to problems identified within STEM, but in relation to broader 'wicked' problems that can benefit from transdisciplinary approaches. Key to the sustainable ecosystem approach is insight into how young people may encounter a wide range of learning experiences and be supported by adults, scientists and policy experts, as well as peers in ways that could lead to future opportunities in personal, academic, professional, and civic realms. This vision requires teachers and organisations to think beyond the bounds of their institutions to consider how collective action at the level of networks can provide opportunities and address inequalities in a way that isolated efforts cannot.

In this deliverable, we therefore take the first steps towards the Roadmap that can underpin this ecosystem approach, by analysing existing practice and resources to understand the criteria that might be used to search out and collate strong STEAM practice, and synthesise this into viable practice and policy recommendations.

In beginning the work in this area, we are clear that we are focused on STEAM practice and thinking

- at the intersecting connection between secondary and tertiary education
- on the use of art-oriented approaches or those using creativity
- practices and thinking explicitly referencing real life settings and grand challenges
- in the context of projects and activities engaging in open schooling and/or open science.

In themselves these provide 'criteria' of sorts by which to begin to gather the map of practices and thinking. However, the specific task for D4.1 is to go beyond these to understand criteria for effective STEAM practice in this bounded realm. These may be thought of as characteristics perhaps or features of strong STEAM practice in this area.

Before entering into the methods and findings of D4.1 in relation to the emergent criteria, there are a number of contextual points to note. There was a thorough discussion at the beginning of the work on D4.1 indicating a need to define what was meant by 'STEAM'. However, Perignat and Katz-Buonincontro (2019) offered early reassurance that this is not currently an easy task. Their seminal, integrative literature

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review of STEAM practice and research shows that most researchers/practitioners in the field will, perhaps obviously, start by articulating the involvement of the sciences, technology, engineering, arts and maths. Beyond this there are then a variety of definitions for the STEAM concept - one of the main points of variance being whether STEAM is defined as transdisciplinary, interdisciplinary, multi-disciplinary or cross-disciplinary. After this point there is much divergence and disagreement as to exactly what this disciplinary integration might involve that defines a particular practice as 'STEAM'. For our purposes, this seminal paper is used as a justification for not attempting an overarching definition of STEAM at the outset of the Road-STEAMer project. It is apparent that it is more likely that this will emerge through the project's development and application of criteria, stemming from this deliverable and out into other deliverables and activities within the project.

Furthermore, a number of findings from Perignat and Katz-Buonincontro (2019) are worthy of note. They demonstrate that there is a lack of knowledge about the deep history and diversity of the arts, as well as the potential for using them side by side with STEM disciplines, as well as an overemphasis on end results. There is an overall lack of measured learning outcomes in the areas of claimed improvement such as creativity, problem-solving, and arts education. Practitioners struggle regarding *how* to integrate the arts. There is also an implicit placing of the arts as a subservient discipline to STEM disciplines. The authors go on to suggest that STEAM scholars and practitioners must shift their language from one that "adds arts to STEM" to describing STEAM as a pedagogical approach that integrates five disciplines equally, and ultimately attempt to agree on a shared definition among researchers and scholars. It is to this wider endeavour within the STEAM field that our Roadmap aims to contribute via policy and practice impact and influence, with the first steps taken via the analysis and emergence of the Road-STEAMer criteria presented below.

2.1 Methods

In order to gather resources for analysis, an overarching approach was taken derived from literature reviewing protocols. This was with the intention of utilising as much rigour and systematicity as was possible but acknowledging the limitations of the resource available. The process therefore proceeded as follows.

The University of Exeter team carried out the main database searches on: Google, Google Scholar and in UoE library keyword search and Education databases (Education database; Education Research Complete; British Education Index; Australian Education Index; ERIC) using the terms:

- STEAM + education, STEAM + education + arts, STEAM + education + creativ*
- STEAM Education + Undergraduate + School, STEAM Education + Secondary + Tertiary, STEAM Education + Higher Education + School, STEAM Education + real-world, STEAM Education + real-life challenge.

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CORDIS was also searched for relevant EU projects and their reports.

University of Exeter searches generated 38 peer-reviewed articles or theses, 2 reports, 12 EU specific reports, 7 books and 2 websites.

All consortium partners were also asked to nominate at least three documents or websites etc that met the project focus on STEAM at the secondary/tertiary intersection, involving arts approaches, and/or open science and open schooling.

Partner searches generated 22 articles, 2 books or book chapters, 4 EU reports and 13 websites or web resources.

Documents and websites were then read against the following inclusion criteria:

- Peer-reviewed articles, documents, initiative documentation and websites which are no older than 10 years
- Dominantly English language with the option to include colleagues' home language publications with translated abstract (however none of the latter were forthcoming)
- Inclusion of criteria, definitions, features or principles of STEAM education
- Either in secondary or tertiary education or at the intersection between the two
- Focused on the use of art-oriented approaches or those using creativity and/or explicit reference to real life settings and grand challenges ("open" common features between open schooling and open science projects or activities).

This process generated 23 articles, 3 reports, 4 books or book chapters, 2 websites and 13 EU projects.

These were then included in a large-scale thematic analysis using the digital tool Mural to share colour-coded criteria from each document or website, and then to thematically organise the criteria into the Road-STEAMer Roadmap relevant criteria. This analysis used the principles of constant comparative analysis (Fram, 2013).

2.2 Results

2.2.1 The initial criteria to be adopted

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From the total of 46 documents, websites and reports, they broke down as follows:

- 35 addressed secondary or tertiary STEAM education or the intersection between the two, with 11 specifically focused on secondary and 8 specifically focused on tertiary
- 14 addressed STEAM in open science/schooling
- 32 addressed art-oriented approaches or those using creativity
- 16 explicitly referenced real life settings and grand challenges (“open” common features between open schooling and open science projects or activities).

It should be noted that all documents always addressed more than one of these categories. The majority of documents addressed the first category with it being a key underpinning principle of the Road-STEAMer project, though some sources included described broader STEAM activity and/or did not specify an empirical focus and provided more open perspectives on the characteristics of STEAM. Due to the breadth of projects including the foci above, it has not been possible to cluster criteria separately in relation to these; however comment is made on the balance of criteria with respect to these key project elements at the end of this section.

Due to the different didactic traditions within different educational cultures, one might expect some differential perspectives on STEAM activities. We have therefore identified where sources are from: Europe, the United States (US), or ‘other international’. 18 of the documents focused on the European context or EU projects; 15 of the documents focused on the US context; 11 of the documents focused outside of these regions. This breadth shows the international presence of the STEAM concept beyond Europe. Where any of the identified criteria appear to be drawn more strongly from one region, this is commented on in the criteria description.

Following the thematic analysis, themes were clustered into these initial groupings to form the draft criteria: Collaboration and relationality, Equity, Inclusion/personalisation/empowerment, Assessment considerations, Acknowledging materiality, Thinking-making-doing, Creativity, Articulating Arts contributions, Disciplinary relationships, Real-world connection. These first analytical clusters are shown here in Figure 1 from the Mural configuration:

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Figure 1 Mural configuration at the end of the thematic analysis

Figure 2 shows the main criteria in combination. It is important to represent the criteria visually in this way to push back against the way in which their inter-relationship might appear from reading the criteria in a linear format below, i.e. that a criterion's weighting is not completely indicative of its importance and that the order that criteria are presented in below is in some ways arbitrary.

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Figure 2 Road-STEAMer criteria in combination

The criteria are described in detail below including all referencing to demonstrate their derivation. They are presented in weighted order with the criteria that occurred most often first, and that which appeared least often last. However, as above, this should not necessarily be taken as an indication of importance as, on occasion, elements that are more subtle and are perhaps 'noticed' less often can be important in underlying ways.

It should be noted that articles are often discursive and argue for the criteria, principles or features that they include. Very few articles, if any, took a statistical approach to proving whether or not STEAM approaches delivered on the criteria argued for. However, this is not a criticism of the articles, but a point to be noted. Many documents were peer-reviewed and deal with STEAM as a complex and sophisticated area of education, offering strong ontological arguments grounded in philosophy. It is perhaps worthy of note that the complexity of the STEAM practices under investigation is reflected in the complexity of the ontological approaches taken beyond a positivist justification.

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The Road-STEAMer criteria are as follows:

2.2.1.1 Collaboration and Relationality (26)

Collaboration and relationality are often articulated within STEAM practices in terms of those involved and their relationships, with an emphasis on the connections between people (Colucci-Gray et al., 2017). Those considered as important are obviously teachers and students, but also external partners (across the STEAM disciplines), local communities, educational stakeholders and local citizens (Columbano et al., 2021: 1 tertiary (tert), 3 EU; CREAM, 2022: 1 secondary (sec)?, 2, 4 EU; OSHub Open Science Hub Network, 2022: 1 sec?, 2, 3 EU; Liston et al., 2022: 1 college, 2, 4 EU; ACE STEAM toolkit).

Mechanisms for facilitating collaboration are also highlighted including engagement through acceptance, as well as the role of technology (Columbano et al., 2021: 1 tert, 3 EU; IMuSciCA, 2019: 1 sec, 3 EU), game-based learning (Liu & Wu, 2022: 1 tert?, 3) and the importance of communication (Liao, 2016: generic, 2, US), the connection to particular art forms for collaboration e.g. music (IMuSciCA, 2019: 1 sec, 3 EU), and the connection between creativity and collaboration (Carter et al., 2018: 1 tert, 4 EU).

Teachers' roles are considered in detail as involving facilitation rather than direction of connected learning through classroom environments which forefront problem solving, authentic tasks, student choice and technology integration (Quigley et al., 2019). Teachers are also seen as adopting multiple roles including that of advisor, counsellor and/or guide (Bautista, 2021: 1 sec + ITE, 3 internat). Teachers are also seen as collaborating with each other, engaging in dialogue, with their manipulation of the classroom environment seen as fundamental to disciplinary inter-relationship (Harris & de Bruin, 2018: 1 sec, 3 Internat).

Various different terminologies are used to refer to collaboration and relationality, with it sometimes listed as a 21st century skill, including: collaboration (Bautista, 2021: 1 sec + ITE, 3 Internat; Graham, 2021: 1 sec, 3 US; Sariemento et al., 2020: 1 tert, 3; Liao, 2016: generic, 2, US) and group working (Columbano et al., 2021: 1 tert, 3 EU); teamwork (Shatunova et al., 2019: 1 sec with tert, 3, 4); interaction (Quigley et al.*).*

Seeing collaboration and relationality as part of a wider STEAM culture featuring multi-modality is highlighted by some as important (Columbano et al., 2021: 1 tert, 3 EU). And perhaps stretching this understanding of 'cultures of collaboration' further, authors writing within the posthuman paradigm also see collaboration and relationality, not just between people, but between people and all others (e.g. environment, planet) as a vital element of STEAM practice related to responding to the issues of the Anthropocene (Guyotte, 2020: 1 sec tert, 4 US).

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2.2.1.2 Thinking-making-doing (25)

This is written thinking-making-doing to emphasise the interactivity of these practices rather than considering them occurring within STEAM in parallel or separately.

Different kinds of thinking are often referred to when authors articulate STEAM practices. These include references to habits of thinking (Foundations of STEAM website: 1, 2?, 3, 4? US); system thinking (Shatunova et al., 2019:1 sec with tert, 3, 4); critical thinking

(Center for STEAM Education Research, Science Communication and Innovation, 2018:

1 CPD sec?, 2 EU; Chung & Li, 2021: 1 second, 3, 4 Hong Kong; Harris & de Bruin, 2018:1 sec, 3 Internat); creative thinking (Harris & de Bruin, 2018:1 sec, 3 Internat); divergent and convergent thinking (Bautista, 2021: 1 sec + ITE, 3 internat).

However, 'thinking' is not seen as an isolated 'brain-based' activity but is also recognised interacting with wider sets of skills to argue for STEAM practices including that they support soft skills (CREAM, 2022: 1 sec?, 2, 4 EU) and that they develop 21st century skills (Graham, 2021: 1 sec, 3 US; ecraft2Learn (2018)1, 2, Finland, EU). Other authors relate STEAM practices to problem solving (Center for STEAM Education Research, Science Communication and Innovation, 2018: 1 CPD sec?, 2 EU), with this defined in terms of the creative, cognitive and interactive (Quigley et al., 2019), and applied to the process of hands-on design and production (Katz-Buonincontro, 2018: 1 sec text, 3 US). STEAM practices are also described as functioning within the more 'hands-on' making and doing practices of multi-modality, unlearning (Columbano et al., 2021: 1 tert, 3 EU), uncertainty management (Shatunova et al., 2019:1 sec with tert, 3, 4) and inquiry-based, real-world learning (Chung & Li, 2021: 1 second, 3, 4 Hong Kong). This reinforces the idea that STEAM is not a sedentary, overly-academic activity.

Making and doing are more explicitly articulated interacting with thinking by authors who emphasise the role of the 'Makers movement' (a cultural trend that places value on an individual's ability to be a creator as well as a consumer) in STEAM practices (CREAM, 2022: 1 sec?, 2, 4 EU), and the importance of granting students an active, constructive and critical role in their learning (Bautista, 2021: 1 sec + ITE, 3 internat). Emphasis is also placed on object-based learning, the use of critique and exhibition and the practice of critical making all derived from the notion of signature pedagogies (where a set of pedagogies is established that is said to represent a particular kind of practice) in the arts (Costantino, 2018: 1 sec + tert, 3 US).

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2.2.1.3 Disciplinary inter-relationship (23)

With the array of disciplinary inter-relationships evidenced in the sources, and the varying definitions of key terms such as inter-, multi-, and transdisciplinary it is impossible to offer clear articulations on this. This section presents the language of disciplinary inter-relationship as is given in the sources. In some cases, disciplinary inter-relationship simply means the inclusion of mixed disciplines within STEAM practices or familiarisation with content outside of the discipline (Foundations of STEAM website 1: 2?, 3, 4? US) or freedom to move between disciplines (Dredd et al., 2021: 1 tertiary, 3, US). It is also thought of in terms of the integration of the arts into curriculum and instruction in science, technology, engineering, and mathematics (Katz-Buonincontro, 2018: 1 sec text, 3 US). When referred to in more complex articulations, this criteria is about there being a new connection of some kind between subjects or skill areas within STEAM practice (Colucci-Gray et al., 2017*;* Johnson-Green et al., 2020: 1 sec, 3, 4 US) or interaction between disciplines (Liu & Wu, 2022:1 tert?, 3). Some argue that this connection making also relates to students' ability to transfer knowledge in some way between disciplines (Huser et al., 2020: 1 sec tert, 3 and 4, US). And others see this connection as grounded in the classroom environment as problem-based, authentic tasks, student choice, technology integration and teacher facilitation (Quigley et al., 2019*).*

Some sources refer to STEAM as encompassing transdisciplinarity (Guyotte, 2020: 1 sec tert, 4, US), some specifically highlighting the role of transdisciplinary approaches to pedagogy (Liston et al., 2022: 1 college, 2, 4 EU; Liao, 2016: generic, 2, US).Others refer to STEAM as encompassing interdisciplinarity topics (Graham, 2021; 1 sec, 3 US; Wan et al., 2020: 1 sec, 3, 4), these authors explain this as immersing students in a diversity of knowledge across the domains of science, technology, engineering, arts and mathematics. Some sources refer to STEAM practices as establishing grounds for cross-disciplinary innovation (Jesinowska et al., 2020: 1 sec, 2, 3 EU). Other authors take an even broader approach and discuss STEAM practices as encompassing inter-, trans- and cross-disciplinary learning (Harris & de Bruin, 2018; 1 sec, 3 Internat).

Other sources make more dynamic comment on the import of disciplinary inter-relationship within STEAM practice. It is seen as related to values, multi-modality, positivity and unlearning (Columbano et al., 2021: 1 tert, 3 EU); as driving change through a process of making, which values experimental and material agency of invention and exchange between arts and science creativities in critical STEAM practices (Burnard & Colucci-Gray, Eds, 2020: 1, 2, 3, 4 Internat); and as developing understanding of disciplinary identities, with personal relevance informing connections between disciplines (Sochaka et al., 2016: 1 tert, 3, 4).

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2.2.1.4 Creativity (15)

Creativity is identified as a key element of STEAM activity. Mirroring wider literature in creativity, creativity in STEAM in the sources identified here is linked to innovation and the production of something novel (Colucci-Gray et al, 2017; Liao et al, 2017), to playfulness (Martinez, 2017, 1, 3, US) and to the concept of flow (immersion in and focus on a particular activity) (Dredd et al, 2021), all of which may be drawn on or developed through STEAM practices.

Some sources describe creativity or creative thinking as a skill that is developed as a result of engaging in STEAM practices (Harris and de Bruin, 2018; Sughanda et al, 2021; Quigley et al, 2019). Elsewhere, creativity is discussed as a kind of 'doing', linked to the 'thinking-making-doing' theme reported in 2.2.1.2 Here, tools and pedagogies such as digital technologies (Katz-Buonincontro, 2018, 1 sec tert, 3 US; Let's STEAM, nd 1, EU) and design thinking (SciCulture, nd, 1 tert, 2, 3, 4, EU) are used creatively as part of STEAM practice. This notion of using creative activities within STEAM is referred to as a means of making connections between disciplines (SciCulture, nd, 1 tert, 2, 3, 4) or in support of collaboration (Martinez, 2017, 1, 3, US). Thus, creativity appears to be seen as a means of supporting other features of STEAM practices as well as being an outcome that is fostered by those practices.

Although not clearly stated as such in any of the sources, one could argue that the connectivity fostered through creative practices in STEAM (Colucci-Gray et al, 2017; Quigley et al, 2019) is one of the means by which STEAM practice can support the links between secondary and tertiary learning and between schools/universities and communities in Open Schooling.

2.2.1.5 Involving real world connection (15)

Many STEAM practices highlight the importance of a real-world context or real-world connection (see e.g. Martinez, 2017, 1, 3, US; Scuolattiva, n.d, 1, 2, 4, EU). Real-world contexts are often linked to problem-solving and inquiry of the type outlined in 3.1.2 (Chung & Li, 2021, 1sec, 3, 4, internat; CREAM project, 2022, 1 sec?, 2, 4, EU) and offer authenticity and purpose to the disciplinary connections being made (Quigley et al, 2019, 1 broad, 4, US; Chung & Li, 2021, 1 sec, 3, 4 internat). The civic space is suggested as a real-world context that offers connectivity between Higher Education learners and the public (Columbano et al, 2021, 1 tert, 3, EU).

Some sources argue that the real-world context offers a means of learners connecting their personal meaning-making (within and between disciplines) to the

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external context (Zhbanova, 2017, 3, 4, US), with a further argument that such personal connection enables identity development, for example enabling girls to identify as change-makers (Wan et al, 2020, 1 sec, 3, 4).

The notion of entrepreneurship appears in STEAM projects in both EU and international settings (OSHub, 2022, Center for STEAM Education Research, Science, COmmunication & Innovation, 2018; Wan et al, 2020, 1 sec, 4, internat). Entrepreneurship is identified as one of the means of connecting STEAM activity to the real-world contexts (Wan et al, 2020, 1 sec, 4, internat; SciCulture, n.d, 1 tert, 2, 3, 4).

2.2.1.6 Inclusion/Personalisation/Empowerment (12)

The notion of inclusivity is developed across a range of STEAM sources, understood in multiple ways. Stemming from the sense that a wider range of interests will be included if the Arts is drawn in to interdisciplinary or transdisciplinary learning in STEM, an assumption is made that STEAM is therefore more inclusive than STEM alone (e.g. ecraft2Learn, 2018, 1?, 2, EU; ACE STEAM toolkit, nd). It is suggested that acceptance is important in the design of STEAM activities, ensuring that participants feel able to fully partake in all aspects of a STEAM process regardless of whether they feel more or less confident in any aspect (Columbano et al, 2021, 1 tert, 3, EU).

Some of the discussion of inclusion is linked to the theoretical concepts of science capital and identity: it is argued that STEAM approaches offer a context in which young people are more likely to be able to develop their identity, including that STEAM is 'for them' (PHERECLOS project, nd, 1 sec tert, EU), and that students' active construction of personal meaning through STEAM leads to greater self-efficacy, confidence and motivation towards socioscientific learning (Bautista, 2018, 1 sec &ITE, 3 internat). This is connected to the concept of empowerment (Huser et al, 2020, 1 sec tert, 3, 4, US), with the argument that STEAM approaches empower young people and promote engagement due to the open-ended nature of many STEAM activities (e.g. problem-based and inquiry learning) and to the real-world contexts to which they may be linked (see 3.1.3 and 3.1.6). Greater inclusion and empowerment via STEAM may, it is argued, lead to those from under-represented groups such as girls developing identities as change-makers (Wan et al, 2020, 1sec, 3, 4, Internat).

2.2.1.7 Acknowledging materiality (10)

One way of defining STEAM is through connection-making, with one of those areas of connection articulated as connection with the environment, bodies and the materiality

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of the spaces in which STEAM practices occur (Colucci-Gray et al, 2017, 1-4, internat). The material nature of the spaces within which STEAM takes place is important and can be arranged to promote effective STEAM practice in various ways (Columbano et al, 2021, 1 tert, 3, EU). These include creating spaces and materials to facilitate visibility of the activity for participants and the public; to use spaces and material resources deliberately, shared between disciplines, in discursive/making spaces; and for participants to be able to change and manipulate their physical environment (Columbano et al, 2021, 1 tert, 3, EU).

A particular material engagement foregrounded in multiple examples of STEAM practices is the use of digital technology. For example, in the context of music, this is assumed to provide opportunities for co-creation and collective activity (Stergiopoulos, 2021, 1 sec, 3. EU). It also enables playful engagement with STEAM via gamification using digital tools (CREAM, 2022, 1 sec?, 2, 4, EU).

Interestingly, the use of digital technologies in STEAM practices appear to be foregrounded rather more in the EU literature than in the US or elsewhere, though limitations of the search parameters and time available mean that this is only a tentative suggestion.

2.2.1.8 Articulating arts' contributions (8)

Where it is articulated, the arts are seen as contributing to socio-cultural elements of STEAM practice, but often in the service of contributing to learners understanding of science concepts, elucidating science concepts and demonstrating their relevance to students' everyday life (Hey-Eun, 2021: 1 sec, 3 Internat). It is important to note here that some authors argue that the arts can be diluted as a consequence of involvement in STEAM, as well as STEM subjects being treated superficially in arts curricula (Johnson-Green et al., 2020: 1 sec, 3, 4 US).

In the US a slightly different understanding exists regarding STEAM through the notion of 'arts integration' (Foundations of STEAM website 1, 2?, 3, 4? US) - a notion akin to what European arts educators might recognise as 'education through the arts' (e.g. Fleming, 2012).

Also, within STEAM practices, whilst the arts are associated with being a catalyst for the creativity and innovation that are necessary for economic competitiveness (Graham, 2021), they are also seen as contributing arts and aesthetic learning intention and meaning (Liu & Wu, 2022: 1 tert?, 3). It is also important that the three core arts processes recognised across all dominant arts disciplines of creating, performing/producing and responding/appreciating are argued as being fundamental across all domains in STEAM practices (Huser et al., 2020: 1 sec tert, 3 and 4, US).

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2.2.1.9 Equity (6)

A values-based approach to STEAM appears to be an important consideration, in terms of both the nature of the practices and processes taking place, and the outcomes that are aimed for. STEAM is, at times, positioned as a resistance to a dominant disciplinary approach to education (Colucci-Gray et al, 2017, 1-4 internat), embodying an affirmative ethical stance (Burnard & Colucci-Gray (Eds), 2020, 1-4 internat; Guyotte, 2020, 1 sec tert, 4, US). This leads to considerations in the design of STEAM activities that deliberately flatten any hierarchy between disciplines and recognise the arts as core subjects alongside STEM with equitable access to time and resources (Allina, 2018, 1 tert, 3, US). It is also argued that enabling students to lead the learning with teachers positioned as facilitators and guides is a common element of STEAM practice (Allina, 2018, 1 tert, 3, US), again enabling a more equitable power relation.

Equity is also highlighted as a possible outcome of STEAM, for example with the production of socially equitable responses to global challenges (Carter et al, 2018, 1 tert, 4, EU). However, this is probably more aspirational than evidence-based to date.

The notion of equity as a key feature of STEAM practices appears to be more prevalent in work at the tertiary level than the secondary level, though this is a tentative conclusion that would benefit from further exploration in this project.

2.2.1.10 Career focus (3)

The notion of STEAM developing skills that young people might need for future careers is articulated as a key outcome in some STEAM projects (Carter et al, 1 tert, 4, EU; ecraft2learn, 2018, 1, 2, EU; Sariemento et al, 2020, 1 tert, 3). This is not necessarily a feature of STEAM practices, though the fostering of interdisciplinary skills (see 3.1.3) that are deemed as key to future employability (Carter et al, 2021, 1 tert, 4, EU) may be.

2.2.1.11 Assessment considerations (3)

Given its key role in education more broadly, it is interesting that assessment does not appear to feature strongly in the STEAM sources explored. Just two sources discussed assessment, and in distinct ways. Indeed, in one project where it is discussed, the focus is on the reduction of assessment of work (CREAM, 1 sec?, 2, 4, EU). Where assessment is discussed, the relationship between assessment and

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teaching is touched on (Sariemento et al, 2020, 1 tert, 3, internat). It may be that this is related to the challenge of assessing relatively open-ended activity, meaning that aspects such as career readiness are identified as a possible focus of assessment, and the notion that assessment should be collective and reflective (Sariemento et al, 2020, 1 tert, 3, internat).

2.2.1.12 Concluding comment

The above list of criteria highlight how some key foci for the Road-STEAMer project already draw out specific criteria for STEAM activity, namely, arts-oriented approaches or those using creativity, and real-life settings or grand challenges. Explicit discussion of arts and creativity elements were apparent in 23 of the sources (articulated arts contributions and creativity criteria combined). Similarly, the use of real-world contexts was explicitly drawn out as a possible criterion from 15 sources when entrepreneurship was combined into this section as a specific connection to the real world. This analysis has therefore enabled us to explore what is meant by these key project foci and clearly articulate the criteria for STEAM practices incorporating these elements.

Open science/open schooling did not feature so strongly in the sources identified in this analysis, though a number of criteria identified can be linked to this concept. The notions of inclusion and accessibility of STEAM, of collaboration, of connectivity with the real world through creative practices, and of the importance of materiality in STEAM all offer insights into how STEAM might contribute to open science/open schooling through the use of effective practices developed using criteria identified here.

2.3 Points of interest from analysis

There are a number of points of interest to pick up on from the analysis and emergent criteria. From a methodological point of view, the term ‘criteria’ is not common within the literature or resources, meaning that often we were looking for characteristics, definitions or features within writing about STEAM. Other conceptual points of interest include:

- Whilst too much should not be implied from this, the weighting of the three largest categories for criteria should be noted: collaboration and relationality; disciplinary inter-relationship; thinking-making-doing. Whether these are in fact the most important and perhaps ‘non-negotiable’ criteria for STEAM assessment for the project will be worthy of attention in the 4.1 co-creation workshop and going forward across the project.
- It is important to note how many different forms of disciplinary inter-relationship there are. This is a richness and perhaps complexity that is difficult to deal with systematically, and will need sophisticated consideration going forward.

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- The role of technology in collaboration and attention to how collaboration is made to work within and beyond formal schooling did not emerge as a dominant criteria in its own right but might be seen as an important connector between other criteria.
- Understanding collaboration as going beyond people collaborating is important; this means understanding the potential for collaboration and dialogue between people and others of all kinds including the environment, technology and other members of the living world.
- Thinking-making-doing are articulated as inter-related not separate processes
- It is vital to consider power relations between disciplines, indicating that all disciplines' core approaches and principles need to be respected.
- In the above descriptions it is clear that some of the means by which STEAM projects may be assessed as effective is based on outcomes such as career attitudes or skills development, compared with other criteria which are more focused on processes of quality STEAM practices.

3. Co-creation workshop

3.1 Workshop method and description

The 4.1 co-creation workshop was run in collaboration with Zentrum für Soziale Innovation (ZSI) colleagues who were required to run the 2.1 co-creation workshop at a similar time. The workshop was open to all Road-STEAMer consortium members online and was recorded for those who could not attend. It was run in line with the Road-STEAMer WP1 participatory methodology principles which are to enable and facilitate dialogue and mutual learning within and between the project consortium and the stakeholder communities, engaging individuals, groups and organisations in the processes and activities of the Road-STEAMer project. This meant working with participatory, dialogic, collaborative and co-creative facilitation processes. These can be seen in evidence in the full plan for both elements of the workshop in Appendix 1. In summary, this included embodied and image-based ice-breaker and wrap up activities; the creative use of digital collaboration tools Mentimeter, Mural and Miro; and facilitation questions designed to provoke appropriate dialogue rather than high-speed agreement.

The 4.1 part of the workshop introduced the criteria as shown above in this deliverable, and asked participants in two breakout groups to discuss and seek clarification as to criteria meanings, make suggestions for changes to language, earmark possible missing sub-elements and to consider how the criteria might relate to each other. Participants were also asked to rank the criteria and to consider which criteria were non-negotiable for them. The 4.1 part of the workshop culminated in the brief introduction of the profiling tool within which the criteria will be used in 4.2 and 4.3 to evaluate STEAM practices. The whole workshop process was caveated with the notion that it would not lead to fundamental changes to the criteria which had

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been generated using a rigorous analysis process, but that the dialogue was about seeking clarity of understanding, honing language and criteria inter-relationships.

3.2 Workshop outcomes

Below is the feedback from the two breakout groups and the mentimeter ranking outcome. Italicised text shows actions that were agreed within the breakout group discussions.

Feedback from Breakout Group 1

- A question was raised about the extent to which policy documents had been included in the analysis and development of the criteria. It was explained that these had been included where they had appeared in the literature search or data capture from the consortium – *agreed to foreground some key EU policy documentation to contextualise the criteria in D4.1.*
- The group discussed the importance of thinking-making-doing, and specifically the role of 'maker-labs'. Consideration was given to whether 'making' should be a criterion in and of itself, but it was agreed that this was an exemplification of thinking-making-doing. *Agreed to review criterion description and consider foregrounding examples of maker-spaces or maker-labs.*
- The importance of industry was raised, with the group discussing the links between industrial relationships in STEAM activities with the real-world connection criterion and the career-focused nature of some STEAM work. Linked to this, the group *discussed and agreed that career-focus could be a sub-category within the real-world connections and that industry links are a good example of this.*
- The group discussed the role of assessment of STEAM activities, with the notion of potentially basing assessment on something concrete rather than an abstract outcome: in other words connecting assessment with the materiality criterion.
- Similarly, discussion explored how the skills identified and described in STEAM practice could be part of the consideration of assessment of/within STEAM practices and also that assessment of the engagement of students could be a consideration. *This discussion extended beyond the findings of the analysis undertaken in 4.1 and point to a possible area of future exploration for the Road-STEAMer roadmap, considering not just the features or criteria of STEAM practices but what that tells us about how learning about and through STEAM might be assessed.*

Group 1's discussions of how they felt the criteria inter-related are shown in Figure 3:

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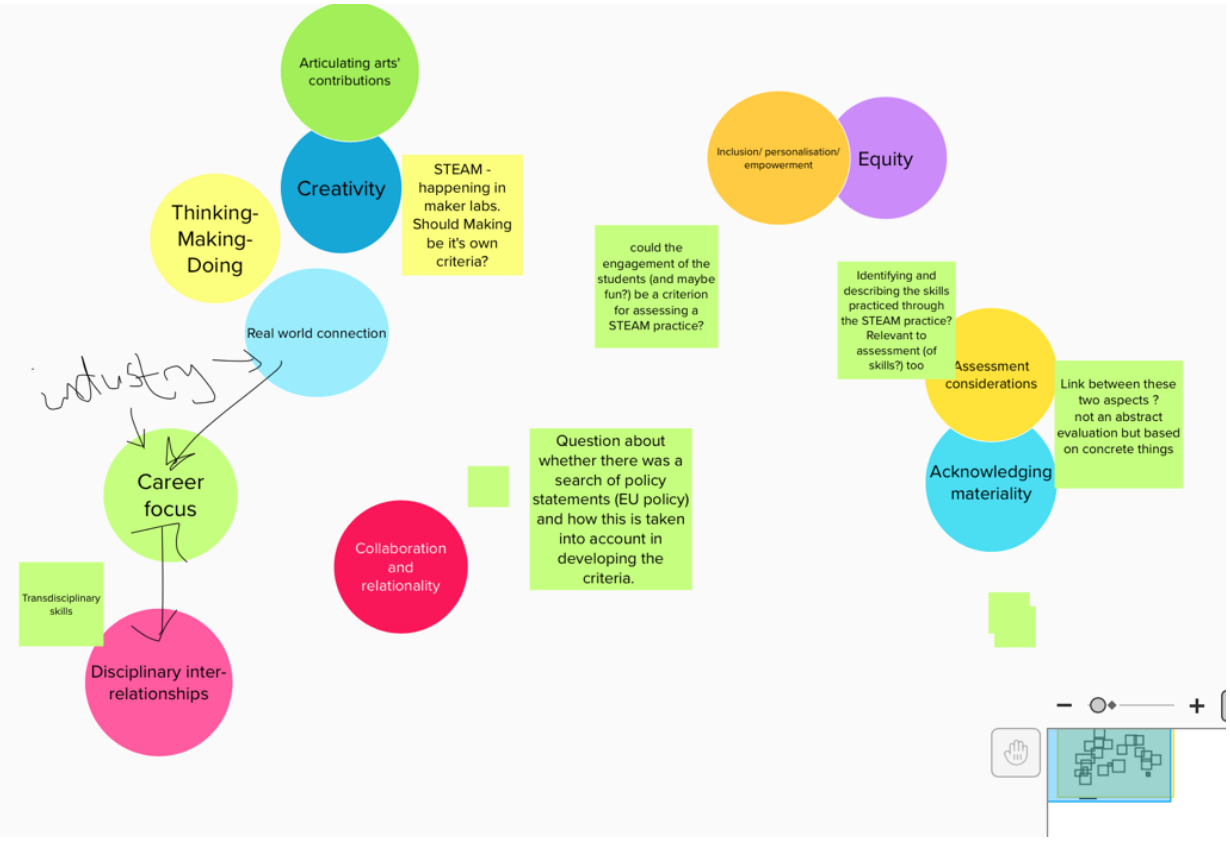

Figure 3: Group 1 visual representation of how criteria related

Feedback from Breakout Group 2

- A question was raised as to the positioning of entrepreneurship. It was explained that this is within the Real World Connections' criteria – *agreed to emphasise as a part of the characterisation of this criteria*
- The group could clearly see connections between Thinking-Making-Doing, Disciplinary Inter-relationships, Creativity and Real World Connections criteria *agreed that this should influence the visual representation in the Mural*
- It was suggested that Thinking-Making-Doing is seen as the main contribution of the Arts *the contribution of the arts criteria went beyond this criteria, and based on the ensuing discussion it was felt that the Arts Contribution criteria would work better as a sub-category within Disciplinary Inter-relationships*
- The idea of problem-solving and open-ended engagement with problems related to creativity – *this could be emphasised in the characteristics description of this criteria to show understanding that problem solving is a key part of creativity*
- There was a suggestion to remove the word relationality from the criterion title Collaboration and Relationality. *Agreed that this would occur and that relationality would just be used within the criteria descriptor.*
- There was a discussion about reconsidering the language used to describe and explain materiality to ensure it is easy to use – *current agreed new wording is acknowledging materials and environment.*

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- There was felt to be a strong relationship in the literature between collaboration and equity – *agreed to positioning these close together within the final visual set of criteria*
- There were discussions about STEAM as oriented toward innovation and the future – *agreed to emphasise link between real-world connection and technology.*

Group 2 discussions of how they felt the criteria inter-related are shown in Figure 4:

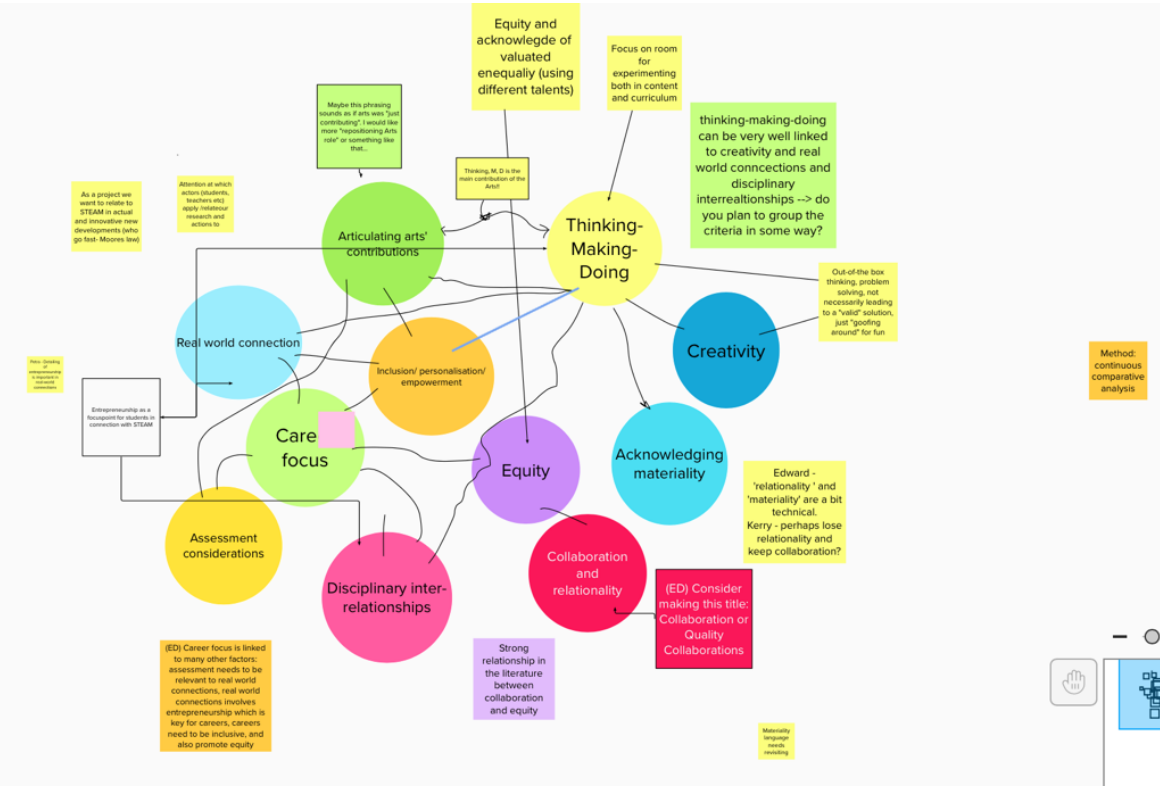

Figure 4: Group 2 visual representation of how criteria related

The mentimeter ranking task outcome is shown below in Figure 5

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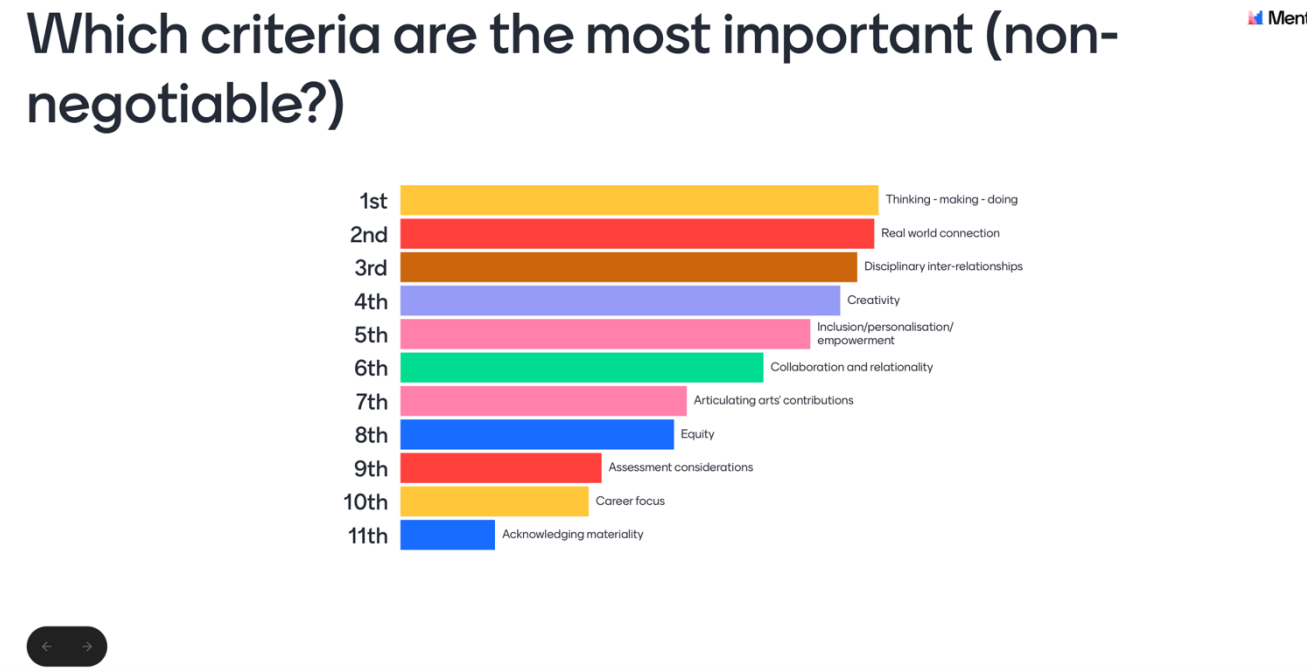

Figure 5: Mentimeter ranking task outcome

Following the workshop, the University of Exeter deliverable authors met to consider the discussions from the two breakout groups and the mentimeter ranking task outcome and associated discussion which they synthesised together. Section 3.3 shows the considered changes that were made to the criteria following the workshop and their synthesis process.

3.3 Changes to criteria following workshop

The criteria are presented in two ways in this section. Firstly, the honed down list showing where some criteria have been made sub-criteria of other criteria and where key parts of criteria definitions have been emphasised. *Italicisation is used within criteria text to demonstrate changes made to criteria characteristics following the workshop.* Secondly, the criteria are shown in visual relationship to each other.

3.3.1 Finalised criteria

Aside from the presentation of Equity as an all-pervading criteria which is presented first, the rest of the core criteria are presented in no particular order. It should be clear that the Contribution of the Arts criteria and the Acknowledging Materials and Environment criteria have been merged under other criteria. Career focus and Assessment Considerations have been removed from the core criteria as discussions showed that they were more long term intended outcomes of good STEAM practice rather than core criteria for STEAM processes. However, careers are mentioned in the 'real-world connection' criteria. This reduces the core criteria from eleven to seven after the workshop.

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Equity

A values-based approach to STEAM appears to be an important consideration, *and workshop discussions and synthesis indicated that this was in fact felt to be an all-pervading criteria which fed through the other core criteria*. Equity was important in terms of the nature of the practices and processes taking place, and the outcomes that are aimed for. STEAM is, at times, positioned as a resistance to a dominant disciplinary approach to education (Colucci-Gray et al, 2017), embodying an affirmative ethical stance (Burnard & Colucci-Gray (Eds), 2020; Guyotte, 2020). This leads to considerations in the design of STEAM activities that deliberately flatten any hierarchy between disciplines and recognise the arts as core subjects alongside STEM with equitable access to time and resources (Allina, 2018). It is also argued that enabling students to lead the learning with teachers positioned as facilitators and guides is a common element of STEAM practice (Allina, 2018), again enabling a more equitable power relation. Equity is also highlighted as a possible outcome of STEAM, for example with the production of socially equitable responses to global challenges (Carter et al, 2018). However, this is probably more aspirational than evidence-based to date. The notion of equity as a key feature of STEAM practices appears to be more prevalent in work at the tertiary level than the secondary level, though this is a tentative conclusion that would benefit from further exploration in this project.

Disciplinary Inter-relationship

In some cases, this simply means the inclusion of mixed disciplines within STEAM practices or familiarisation with content outside of the discipline (Foundations of STEAM website) or freedom to move between disciplines (Dredd et al., 202). It is also thought of in terms of the integration of the arts into curriculum and instruction in science, technology, engineering, and mathematics (Katz-Buonincontro, 2018). When referred to in more complex articulations, this criteria is about there being a new connection of some kind between subjects or skill areas within STEAM practice (Colucci-Gray et al., 2017*;* Johnson-Green et al., 2020) or interaction between disciplines (Liu & Wu, 2022). Some argue that this connection making also relates to students' ability to transfer knowledge in some way between disciplines (Huser et al., 2022). And others see this connection as grounded in the classroom environment as problem-based, authentic tasks, student choice, technology integration and teacher facilitation (Quigley et al., 2019*).*

Some sources refer to STEAM as encompassing transdisciplinarity (Guyotte, 2020), some specifically highlighting the role of transdisciplinary approaches to pedagogy (Liston et al., 2022; Liao, 2016). Others refer to STEAM as encompassing interdisciplinarity topics (Graham, 2021; Wan et al., 2020), these authors explain this as immersing students in a diversity of knowledge across the domains of science, technology, engineering, arts and mathematics. Some sources refer to STEAM

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practices as establishing grounds for cross-disciplinary innovation (Jesinowska et al., 2020). Other authors take an even broader approach and discuss STEAM practices as encompassing inter-, trans- and cross-disciplinary learning (Harris & de Bruin, 2018).

Other sources make more dynamic comments on the import of disciplinary inter-relationship within STEAM practice. It is seen as related to values, multi-modality, positivity and unlearning (Columbano et al., 2021); as driving change through a process of making, which values experimental and material agency of invention and exchange between arts and science creativities in STEAM practices (Burnard & Colucci-Gray, Eds, 2020); and as developing understanding of disciplinary identities, with personal relevance informing connections between disciplines (Sochaka et al., 2016).

Articulating Arts' Contribution

This has now been positioned as a sub-criteria of disciplinary inter-relationships as it was felt unlikely that all good STEAM practice would necessarily articulate the arts' contribution. However we should remain alert to it as it stems from the power imbalances that the arts experience in STEAM work and which this project can contribute towards re-balancing.

Where it is articulated, the arts are seen as contributing to socio-cultural elements of STEAM practice, but often in the service of contributing to learners' understanding of science concepts, elucidating science concepts and demonstrating their relevance to students' everyday life (Hey-Eun, 2021). It is important to note here that some authors argue that the arts can be diluted as a consequence of involvement in STEAM, as well as STEM subjects being treated superficially in arts curricula (Johnson-Green et al., 2020).

In the US a slightly different understanding exists regarding STEAM through the notion of 'arts integration' (Foundations of STEAM website) - a notion akin to what European arts educators might recognise as 'education through the arts' (e.g. Fleming, 2012).

Also, within STEAM practices, whilst the arts are associated with being a catalyst for the creativity and innovation that are necessary for economic competitiveness (Graham, 2021), they are also seen as contributing arts and aesthetic learning intention and meaning (Liu & Wu, 2022). It is also important that the three core arts processes recognised across all dominant arts disciplines of creating, performing/producing and responding/appreciating are argued as being fundamental across all domains in STEAM practices (Huser et al., 2020).

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Collaboration

Whilst relationality is still recognised as part of the characteristics of this criteria, the term has been removed from the criteria to make the naming more accessible. Collaboration and relationality are often articulated within STEAM practices in terms of those involved and their relationships, with an emphasis on the connections between people (Colucci-Gray et al., 2017). Those considered as important are obviously teachers and students, but also external partners (across the STEAM disciplines), local communities, educational stakeholders and local citizens (Columbano et al., 2021; CREAM, 2022; OSHub Open Science Hub Network, 2022; Liston et al., 2022; ACE STEAM toolkit).

Mechanisms for facilitating collaboration are also highlighted including engagement through acceptance, as well as the role of technology (Columbano et al., 2021; IMuSciCA, 2019), game-based learning (Liu & Wu, 2022) and the importance of communication (Liao, 2016), the connection to particular art forms for collaboration e.g. music (IMuSciCA, 2019), and the connection between creativity and collaboration (Carter et al., 2018).

Teachers' roles are considered in detail as involving facilitation rather than direction of connected learning through classroom environments which forefront problem solving, authentic tasks, student choice and technology integration (Quigley et al., 2019). Teachers are also seen as adopting multiple roles including that of advisor, counsellor and/or guide (Bautista, 2021). Teachers are also seen as collaborating with each other, engaging in dialogue, with their manipulation of the classroom environment seen as fundamental to disciplinary inter-relationship (Harris & de Bruin, 2018).

Different terminologies are used to refer to collaboration and relationality, with it sometimes listed as a 21st century skill, including: collaboration (Bautista, 2021; Graham, 2021; Sariemento et al., 2020; Liao, 2016) and group working (Columbano et al., 2021); teamwork (Shatunova et al., 2019); interaction (Quigley et al., 2019*).*

Seeing collaboration and relationality as part of a wider STEAM culture featuring multi-modality is highlighted by some as important (Columbano et al., 2021). And perhaps stretching this understanding of 'cultures of collaboration' further, authors writing within the posthuman paradigm (a recent paradigm shift which aims to de-centre humans and their influence, and offer more influence to the other-than-human) also see collaboration and relationality, not just between people, but between people and all others (e.g. environment, planet) as a vital element of STEAM practice related to responding to the issues of the Anthropocene (Guyotte, 2020).

Involving Real World Connections

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Many STEAM practices highlight the importance of a real-world context or real-world connection (e.g. Martinez, 2017; Scuolattiva, n.d,). In some cases this can be through exploration of cutting edge issues or 'wicked problems' such as climate change (SciCulture, nd) and offer a strong point of connection with wider EU policy such as the EU Strategy for Enhancing Green Skills (European Commission, 2020). Real-world contexts are often linked to problem-solving and inquiry of the type outlined in above Chung & Li, 2022; CREAM project, 2022) and offer authenticity and purpose to the disciplinary connections being made (Quigley et al, 2019; Chung & Li, 2021). The civic space is suggested as a real-world context that offers connectivity between Higher Education learners and the public (Columbano et al, 2021).

Some sources argue that the real-world context offers a means of learners connecting their personal meaning-making (within and between disciplines) to the external context (Zhbanova, 2017), with a further argument that such personal connection enables identity development, for example enabling girls to identify as change-makers (Wan et al, 2020).

The notion of entrepreneurship appears in STEAM projects in both EU and international settings (OSHub, 2022, Center for STEAM Education Research, Science, Communication & Innovation, 2018; Wan et al, 2020). Entrepreneurship is identified as one of the means of connecting STEAM activity to the real-world contexts (Wan et al, 2020; SciCulture, n.d,). *Entrepreneurship and technology use were also emphasised as key parts of the real world connections criteria, in the workshop discussions.*

Career Focus

One outcome of STEAM projects articulate in the literature is that STEAM is able to develop skills young people might need for future careers. This is a further example of a potential real-world connection, though it is not necessarily a feature of steam practices, rather an outcome. (Carter et al, 2021; ecraft2learn, 2018; Sariemento et al, 2020).

Thinking-making-doing

This is written thinking-making-doing to emphasise the interactivity of these practices rather than occurring within STEAM in parallel or separately.

Different kinds of thinking are often referred to when authors articulate STEAM practices. These include references to habits of thinking (Foundations of STEAM website); system thinking (Shatunova et al., 2019); critical thinking (Center for STEAM Education Research, Science Communication and Innovation, 2018; Chung & Li, 2021; Harris & de Bruin, 2018); creative thinking (Harris & de Bruin, 2018); divergent and convergent thinking (Bautista, 2021).

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However, ‘thinking’ is not seen as an isolated ‘brain-based’ activity but is also recognised interacting with wider sets of skills to argue for STEAM practices including that they support soft skills (CREAM, 2022) and that they develop 21st century skills (Graham, 2021; ecraft2Learn (2018)). Other authors relate STEAM practices to problem solving (Center for STEAM Education Research, Science Communication and Innovation, 2018), with this defined in terms of the creative, cognitive and interactive (Quigley et al., 2019), and applied to the process of hands-on design and production (Katz-Buonincontro, 2018). STEAM practices are also described as functioning within the more ‘hands-on' making and doing practices of multi-modality, unlearning (Columbano et al., 2021), uncertainty management (Shatunova et al., 2019) and inquiry-based, real-world learning (Chung & Li, 2021). This reinforces the idea that STEAM is not a sedentary, overly-academic activity.

Making and doing are more explicitly articulated interacting with thinking by authors who emphasise the role of the ‘Makers movement’ (a cultural trend that places value on an individual's ability to be a creator as well as a consumer) in STEAM practices (CREAM, 2022), and the importance of granting students an active, constructive and critical role in their learning (Bautista, 2021). Emphasis is also placed on object-based learning, the use of critique and exhibition and the practice of critical making all derived from the notion of signature pedagogies in the arts (Costantino, 2018).

Acknowledging Spaces, Materials and Environments

In the workshop discussions it was agreed that this was not a criteria in its own right but was very much reflected as a sub-criteria of the Thinking-Making-Doing criteria; in fact as part of the ‘glue’ which integrates the three activities together.

One way of defining STEAM is through connection-making, with one of those areas of connection articulated as connection with the environment, bodies and the materiality of the spaces in which STEAM practices occur (Colucci-Gray et al, 2017). The material nature of the spaces within which STEAM takes place is important and can be arranged to promote effective STEAM practice in various ways (Columbano et al, 2021). These include creating spaces and materials to facilitate visibility of the activity for participants and the public; to use spaces and material resources deliberately, shared between disciplines, in discursive/making spaces; and for participants to be able to change and manipulate their physical environment (Columbano et al, 2021).

A particular material engagement foregrounded in multiple examples of STEAM practices is the use of digital technology. For example, in the context of music, this is assumed to provide opportunities for co-creation and collective activity (Stergiopoulos, 2021). It also enables playful engagement with STEAM via gamification using digital tools (CREAM, 2022).

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Interestingly, the use of digital technologies in STEAM practices appear to be foregrounded rather more in the EU literature than in the US or elsewhere, though limitations of the search parameters and time available mean that this is only a tentative suggestion.

Creativity

Creativity is identified as a key element of STEAM activity. Mirroring wider literature in creativity, creativity in STEAM in the sources identified here is linked to innovation and the production of something novel (Colucci-Gray et al, 2017; Liao et al, 2017), to playfulness (Martinez, 2017) and to the concept of flow (Dredd et al, 2021), all of which may be drawn on or developed through STEAM practices. *The workshop discussion also highlighted the relationship between problem-solving and open-ended engagement with problems as facets of creativity that can be linked to STEAM practices.*

Some sources describe creativity or creative thinking as a skill that is developed as a result of engaging in STEAM practices (Harris and de Bruin, 2018; Sughanda et al, 2021; Quigley et al, 2019). Elsewhere, creativity is discussed as a kind of 'doing', linked to the 'thinking-making-doing' theme. Here, tools and pedagogies such as digital technologies (Katz-Buonincontro, 2018; Let's STEAM, nd) and design thinking (SciCulture, nd) are used creatively as part of STEAM practice. This notion of using creative activities within STEAM is referred to as a means of making connections between disciplines (SciCulture, nd) or in support of collaboration (Martinez, 2017). Thus, creativity as a main criteria appears to be seen as both a means of supporting other features of STEAM practices as well as being an outcome that is fostered by those practices.

Although not clearly stated as such in any of the sources, one could argue that the connectivity fostered through creative practices in STEAM (Colucci-Gray et al, 2017; Quigley et al, 2019) is one of the means by which STEAM practice can support the links between secondary and tertiary learning and between schools/universities and communities in Open Schooling.

Inclusion, Empowerment and Personalisation

The notion of inclusivity is developed across a range of STEAM sources, understood in multiple ways. Stemming from the sense that a wider range of interests will be included if the Arts is drawn in to interdisciplinary or transdisciplinary learning in STEM, an assumption is made that STEAM is therefore more inclusive than STEM alone (e.g. ecraft2Learn, 2018; ACE STEAM toolkit, nd). It is suggested that acceptance is important in the design of STEAM activities, ensuring that participants feel able to fully partake in all aspects of a STEAM process regardless of their levels of confidence in any aspect (Columbano et al, 2021).

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Some of the discussion of inclusion is linked to the theoretical concepts of science capital and identity: it is argued that STEAM approaches offer a context in which young people are more likely to be able to develop their identity, including that STEAM is 'for them' (PHERECLOS project), and that students' active construction of personal meaning through STEAM leads to greater self-efficacy, confidence and motivation towards socioscientific learning (Bautista, 2018). This is connected to the concept of empowerment (Huser et al, 2020), with the argument that STEAM approaches empower young people and promote engagement due to the open-ended nature of many STEAM activities (e.g. problem-based and inquiry learning, see creativity criterion above) and to the real-world contexts to which they may be linked. Greater inclusion and empowerment via STEAM may, it is argued, lead to those from under-represented groups such as girls developing identities as change-makers (Wan et al, 2020).

3.3.2 Visual representation showing relationships between criteria

Figure 6 shows the visual representation of the criteria in relation to each other. The key take home messages from this are that Equity is an all-pervading core criteria, with the other 6 criteria within the oval all core criteria.

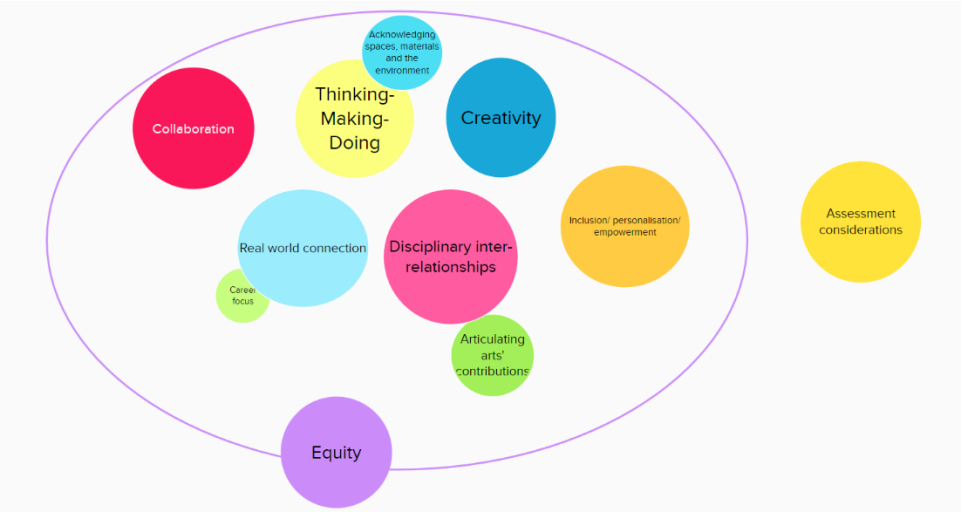

Figure 6: visual representation showing relationships between criteria

A note on Assessment

As highlighted above, following the workshop Assessment has been removed as a criterion for the Road-STEAMer analysis of STEAM practices. Given its key role in education more broadly, it is interesting that assessment does not appear to feature strongly in the STEAM sources explored. Just two sources discussed assessment, and in distinct ways. Indeed, in one project where it is discussed, the focus is on the reduction of assessment of work (CREAM, nd). Where assessment is discussed, the relationship between assessment and teaching is touched on (Sariemento et al, 2020). It may be that this is related to the challenge of assessing relatively open-ended activity, meaning that aspects such as career readiness are identified as

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a possible focus of assessment, and the notion that assessment should be collective and reflective (Sariemento et al, 2020). However, the workshop discussion showed that the question of assessment of/through STEAM practices is of interest, and although not a criterion for the project's analysis in future deliverables, the project will be mindful of this as a possible need for further development and exploration as the roadmap for STEAM is laid out.

4. Conclusion

This deliverable explains the process used to identify a set of criteria which can be used to analyse STEAM practices in real-life use cases, to explore and understand how STEAM is currently practiced across Europe. Using the Road-STEAMer co-creation methodology, both published literature and published projects were identified using a combination of literature searching and contributions from colleagues across the consortium. These were analysed thematically and categorised with respect to key areas of interest with respect to STEAM identified for the project to ensure relevance to the focus areas of open science-open schooling, the role of the Arts, the boundary between secondary and tertiary education, and the interaction with the real world. The following criteria were identified:

- **Collaboration**
- **Disciplinary Inter-relationships**
- **Thinking-Making-Doing**
- **Creativity**
- **Real-world Connection**
- **Inclusion/Personalisation/Empowerment**

Equity as an underlying value of all STEAM practices.

It is interesting to note that whilst not rising to the top as key criteria, concepts such as digital technologies, open-ended activities, problem finding and solving are spread across and within the key criteria. This is worthy of note for when the criteria and their inter-relationship are applied in other project deliverables, especially within work package 4.

This deliverable shows the Road-STEAMer criteria at the end of project Month 6, in February 2023. Whilst the project does not include revisiting this deliverable and amending it in response to learning in the project, the deliverable authors would like to suggest that the criteria are considered fluid and responsive enough to be amended during the project's lifetime. In particular the role of digital technologies remains latent within the criteria; this is a dynamic to remain alert to, particularly in light of key European policy such as 'Europe's Digital Decade' which focuses on digital society and digital technologies. This policy focus will include learners learning about, learning with, and learning through digital technologies in ways that connect closely with the Road-STEAMer criteria for STEAM practices. For example, real-world connections, collaboration, inclusion, creativity and thinking-making-doing and disciplinary inter-relations can all be supported through and exploit and develop understanding of the digital.

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Similarly, though largely linked to the real-world connection criterion in the descriptions above, the role of a range of facets of STEAM practice (such as disciplinary inter-relationship, empowerment and collaboration) in supporting policy areas such as the development of ‘green skills’ (European Commission, 2020) is an important area for the project to maintain a focus on. In the next steps of the project, we suggest that these elements are broadly considered in the analysis of practices and development of the roadmap.

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APPENDIX 1

Road-STEAMer Co-creation workshop for Tasks 2.1 and 4.1

Thursday 19 January 2023

2 hours

Online – RECORDED

Colleagues asked to pre-read D2.1 and D4.1

Type of Activity	Tasks
Icebreakers - HW & KC 10 minutes	Mentimeter familiarisation exercise – which cat are you this morning? https://www.mentimeter.com/app/presentation/al91r2f35o3qbcxuneegk9uiicwtcfhs/eg2xghm7y3nf/edit Temperature taking - see the middle of the table/screen as very hot/positive and the edge of the table/screen as very cold/negative. Place your hand on the table/screen in terms of how positive/negative you currently feel about the state of STEAM education. Embodying STEAM – using one hand to represent STEM and a digit from the other hand the Arts, create a hand sculpture to represent the relationship between STEM and A in STEAM.

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Dialogue around core questions 2.1 questions/findings: What is missing in the desktop research findings? What would you recommend based on these findings? ⟶ Top 5 recommendations 50 mins	Two groups, one moderated by Elisabeth and one by Claudia MiroBoard: https://miro.com/app/board/uXjVP7PBaUc=/ Group 1: Left side of mindmap Group 2: Right side of mindmap 5 min Brief introduction to preliminary findings, introduction to Miro 5 min of individual reflection ⟶ check what is missing and complement on sticky notes 30 min discussion: what is missing? top 5 recommendations, what can be done? 10 min plenary short presentation and discussion
Dialogue around core questions 4.1 questions/findings: 25 mins (KC lead)	Task 1 Introduce criteria in Mural briefly (Kerry & Lindsay within each group) Kerry's group (Lucy to be in this group): https://app.mural.co/t/ssis9878/m/ssis9878/1668530576602/2f47097d7da8983a68cfa6297eb742cfe3efce96?sender=ubdd818ba561ec83cd5d81454 Harriet's group (Lindsay to be in this group): https://app.mural.co/t/ssis9878/m/ssis9878/1673434675063/30d8d2d283ddabbdb417c008869b29817caec558?sender=ubdd818ba561ec83cd5d81454 Work in breakout groups in Mural to A discuss and understand the criteria developed - facilitated by UoE team member in each room, all taking notes into the Mural to track thinking B make suggestions for changes to phrasing (NB changes to criteria themselves not possible) *NB*

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	q of whether criteria are processes or outcomes could come up here C carry out a positioning exercise to understand the criteria in relation to each other (try to avoid ranking)
Mentimeter and criteria application modelling 25 mins (HW lead)	Task 2 A Whole group mentimeter exercise to see which criteria colleagues would position as non-negotiable for STEAM practice. https://www.mentimeter.com/app/presentation/alni517fgxwth7mo7cjcckowxicu1wcj/yehi4znr2fhp/edit B Discussion of profiling tool – what kind of model will we need to evaluate STEAM practices? Breakout groups - Sophie and Claudia in each group introduce profiling tool. Ask about models? Any advice for applying criteria in practice (other models?) Group One Sophie Harriet Lindsay Group Two Claudia Kerry Lucy
Wrap up KC Thank all participants for their contributions. 10 mins	Repeat temperature taking exercise

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