Road STEAMer conceptual framework

Deliverable 2.2

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Lead Partner: University of Exeter
Authors: Lucy Yeomans; Kerry Chappell; Lindsay Hetherington; Sabrina Bresciani; Elisabeth Unterfrauner; Claudia Fabian; Pavlos Koulouris
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List of Abbreviations

Abbreviation	Description
AI	Artificial Intelligence
EA	Ellinogermaniki Agogi
EC	European Network Science Centres and Museums (Ecsite)
ENG	Engineering Ingegneria Informatica
ESHA	European School Heads Association
EU	European Union
GDPR	General Data Protection Regulation
K-12	Kindergarten to 12th grade – compulsory education range in United States and Canada
LC	The Lisbon Council for Economic Competitiveness and Social Renewal asbl.
OECD	Organisation for Economic Co-operation and Development

PAN	Panteion
PO	Politecnico di Milano
STEAM	Science, Technology, Engineering, Arts and Mathematics
SV	Science View
TR	TRACES
UM	University of Malta
UoE	The University of Exeter
WP	Work Package
WP1	Coordination and support for dialogue and mutual learning work package
WP2	STEAM context, concepts and conditions work package
WP3	Analysis of STEAM policy gaps and needs work package
WP4	The landscape of STEAM practices work package
WP5	Synthesis of the STEAM roadmap work package
WP6	Dissemination and Exploitation work package
WP7	Management work package
ZSI	Zentrum für Soziale Innovation

Revision History

Revision	Date	Author	Organisation	Description
0.1	1	LY, KC & LH	UoE	Initial draft
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0.3	-	-	-	Initial draft
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0.5	14.08.23	LY, KC & LH	UoE	Revision, final formatting and pdf submission

Abstract

This deliverable develops a comprehensive conceptual framework for STEAM which synthesises the breadth of theoretical approaches linked to STEAM practice in the literature in relation to the Road-STEAMer foci. Based in systematic literature review protocols, a literature search was conducted to identify resources in which STEAM was theorised or conceptualised: using artistic approaches involving creative thinking and applied arts (the "A" in STEAM); connecting to open schooling and open science; at the secondary-tertiary interconnection. Papers were thematically analysed, with the heart of the Road-STEAMer conceptual framework emerging as grounded in relationality. Further, the analysis produced a set of four groups of approaches, namely 'experiential, real-world interaction approaches', 'human psychological and cognitive approaches', 'social, spatial and material interconnectivity approaches' and 'cultural and equity approaches'. These groupings were analysed and explored to identify how each connects to the criteria for mapping and analysing STEAM practice described in deliverable D4.1 for this project. The conceptual framework thus developed was then refined using the Road-STEAMer co-creation methodology via a co-creation workshop with academics and practitioners. The Road-STEAMer conceptual framework therefore consists of a) an underpinning concept of STEAM as relational, b) a set of four thematic groups of theoretical approaches, which enable c) the spotlighting of key criteria for effective STEAM practice. Examples of how this framework enables well-grounded conceptual understanding of STEAM practices from previous EU-funded projects are included. We argue that, with further work to be undertaken on making these ideas public-facing and accessible, this broad conceptual framework will be of use to policymakers and practitioners in creating the conditions for, and designing, STEAM practice that is effective in achieving key goals identified in deliverable D2.1.

1. Introduction

1.1 About Road-STEAMer

STEAM Education Europe is an open group developed in the framework of the Road-STEAMer EU-funded project. It will function both as a forum for the proper exchange of ideas, smart practices in STE(A)M education and policy and as a channel for the sharing or the project's results.

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

This deliverable sits within Work Package 2, the main objectives of which are to conduct a comprehensive analysis of STEAM concepts, contexts, and conditions, which will:

a) cover the wider socioeconomic context and relevant needs in Europe;
b) on this background, develop a comprehensive conceptual framework for STEAM covering its various aspects and potential; and
c) analyse the various conditions and requirements for the effective adoption of STEAM approaches in education, such as those relating to the curriculum, teacher training, school organization, etc.

a) is achieved in deliverable D2.1. This deliverable, D2.2, is set within the socioeconomic context and current relevant European needs as laid out there. The results of deliverable D2.1 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 and 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. This is to counteract some of the identified gaps in participation and attainment in STEM and to meet the identified needs. These include a need for more inclusive pedagogy, and for this, the integration of the arts in STEM education is promising. Holistic STEAM education with emotional and appealing materials and approaches where 'art' is a way of enhancing self-confidence and facilitating the development of personal opinions and critical thinking may lead to more scientists in the long term, which resulted as another identified need.

Building on the results of deliverable D2.1, the deliverable at hand aims to develop a comprehensive conceptual framework for STEAM aiming to cover all its aspects and promised positive impacts in relation to the core foci of the Road-STEAMer project:

- the use of artistic approaches to STEM involving creative thinking and applied arts (the "A" in STEAM);

- moving beyond "just hard science", by encompassing the world of technology and everyday life aspects which are not always obviously related to science for the student (connecting to open schooling and open science); and
- reasons why STEAM can prove particularly useful in the analysed socioeconomic context in order to address the identified needs.

The development of this conceptual framework is fundamentally necessary to the future development of STEAM in Europe. Prior searches show that European Union (EU) policy literature does not provide a single definition of STEAM. A number of descriptions can be found in various documents, which generally include two aspects. On the one hand, the "A" in STEAM is described as including a range of distinct elements such as "*arts*", "*applied arts*", "*social sciences and the humanities*", as well as "*creative thinking*", "*real-world problem-solving*" and "*practical applications*", and more generally an "*interdisciplinary approach*". On the other hand, benefits of adopting a STEAM approach are identified mainly in the field of STEM education, including the promotion of "*creativity*", "*innovation*", "*transversal competences*", "*soft skills*", "*communication*", "*critical thinking*", "*collaboration*", as well as "*increasing student engagement*". For example, in the Horizon Europe call topic under which Road-STEAMer is being funded, STEAM is defined as "*the use of artistic approaches to STEM involving creative thinking and applied arts (the "A" in STEAM)*" (European Commission). Further information on the conceptualization of STEAM in EU policy documents as well as in relevant work by the Organization for Economic Cooperation and Development (OECD) can be found in the Appendix to this document.

Given this lack of definition of STEAM and the conceptualisations that might underpin it, the activity within this deliverable is vital to fill this gap and to lay rigorous theoretical groundwork for the mapping exercise that is to follow.

The study methods and tools used in this task follow the methodological pattern for WP2, with the work on the conceptual framework informed by a dedicated co-creation workshop, concluding with the delivery of deliverable D2.2.

It should be noted that in responding to the aims and objectives laid out above, this deliverable has been written to explain how the conceptual framework has been rigorously, academically developed, and is presented here using the language and style of the theoretical papers on which the analysis is grounded. Moving forward there is a need to make section 4 of this deliverable accessible to policymakers and practitioners alike; this warrants developing resources which will be housed on the public pages of the Road-STEAMer website, and which will be used in the future as part of ongoing activities in WP1-7.

2. Methodological approach and early-stage results.

2.1 Methods

To gather resources for analysis, an overarching approach was used, derived from systematic literature review protocols. This was with the intention of utilising as much rigour and systematicity as was possible but acknowledging the limitations of the resources available. The process therefore proceeded as follows.

The University of Exeter team conducted searches on the 2nd of January 2023 and included four databases: EBSCO (including E - Journals, British Education Index, Education Research Complete, ERIC), International Bibliography of Social Sciences (IBSS), Scopus, and Web of Science.

Syntax (Search in title, abstract and keywords)

(TITLE-ABS-KEY (st*eam* OR *"Science, Technology, Engineering, Arts, and Mathematics"* OR s*tem* AND *art* OR creativ*) AND TITLE-ABS-KEY (*real-world* OR *everyday* OR *real* AND *life* OR *"open schooling"* OR “*open science"* OR c*ommunity*) AND TITLE-ABS-KEY (*secondary* OR *tertiary* OR h*igher* OR *school* OR c*ollege* OR *university* OR *undergraduate* OR *outreach* AND educat*))

After conducting this research, we exported the results to Endnote (v.20) and, after deleting duplicates, we exported the references to an Excel spreadsheet. All consortium partners were also asked to nominate articles that met the project focus on STEAM at the secondary/tertiary intersection, involving arts approaches, and/or open science and open schooling and which included a theoretical framework. These articles were added to the Excel spreadsheet, with duplicates removed. This process generated 139 articles.

The University of Exeter, along with consortium partners from ZSI and the University of Malta then screened the titles and abstracts of each reference and organised them into two categories: include or exclude*. To be included, the references must:

- Have the full text available
- 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
- On the topic of the paper on STEAM in an educational setting (formal, informal or nonformal)
- Make reference to a theoretical or conceptual framework, or mention of a 'theory' or 'construct' or 'concept' which we may be used to look at STEAM practice

* Education phase (i.e., secondary-tertiary transitions) was not used as an inclusion/exclusion criterion to allow for the inclusion of theories or concepts that could be generically useful across education phases for STEAM work.

After applying this inclusion criteria, this process generated 51 articles and 43 potential theoretical frameworks. Some theoretical frameworks were present in more than one article, while some articles included reference to multiple theoretical frameworks.

The University of Exeter team then undertook an analysis of the 43 theoretical frameworks identified in the previous step. The initial step was to remove firstly those which did not have a strong theoretical heritage in an identifiable conceptual framework of some kind; and secondly concepts/theories drawn from articles where the theory or concept was not well defined or clear. This led to 31 frameworks identified and summarised onto the digital tool mural (www.mural.co).

The University of Exeter team then met together to undertake a thematic analysis mural in a dialogic process which developed the final shortlist of theoretical frameworks. This analysis used the principles of constant comparative analysis (Fram, 2013) and resulted in the four groups detailed below.

2.2 Early-stage results

Before analysing the theoretical frameworks in detail, a collaborative dialogue between project partners led to a provisional conceptualisation of STEAM based on a *relational* ontological stance in which relations between entities are seen as a core part of what they are in reality, and which contribute to their manifestation (see section 4.1). We therefore began to consider a framework for the Road-STEAMer project placing the concept of *relationality* at the heart of STEAM activity.

The process of initial screening described above left us with 26 theoretical frameworks to analyse thematically through a discursive process in which each framework was considered, searching for similarities and differences between them with the aim of drawing out key 'umbrella' themes within which each theoretical framework might sit. Bearing in mind our prior identification of 'relationality' as a key concept within our conceptualisation of STEAM, it was important to bear in mind the nature of the relations each theoretical framework incorporated.

This analytical approach led to grouping and re-grouping of these frameworks until four broad sets of theoretical approaches that encapsulated these theoretical frameworks were identified. These sets of approaches, namely 'experiential real-world interactions', 'human psychological and cognitive', 'social, spatial and material interconnectivity', and 'cultural and equity' each incorporated between 6-9 of the theoretical frameworks used in STEAM activity identified in the initial literature search. Figure 1 shows a screenshot of the mural following this initial analytical process. Figure 2 shows the frameworks associated with each of the four analytical groups. It should be noted that in this coding process, two key ideas were coded under two of these umbrella approaches, as they could be deemed relevant to either. These are flow state, and space-time and culture (see figure 6). Section 4.2.1 describes in more detail the theoretical frameworks included in the framing of the final sets of approaches following the co-creation workshop.

Figure 1 Mural image showing the outcomes of the initial thematic analysis

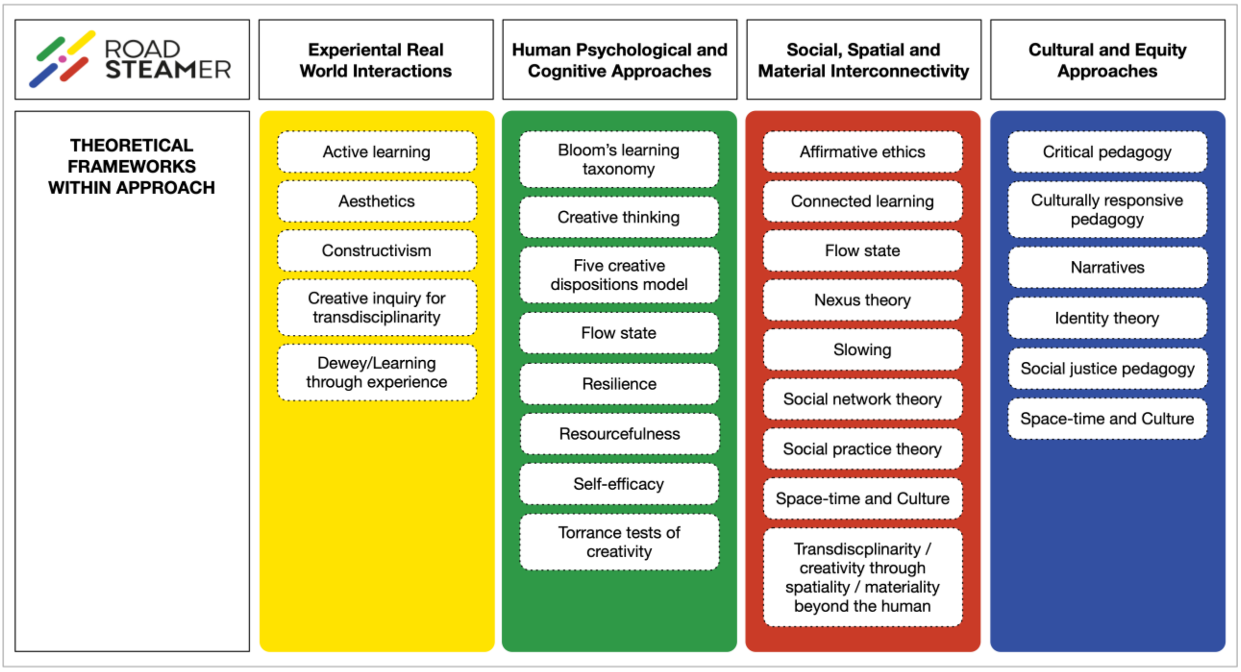


Figure 2 The four groups of theoretical approaches derived from thematic analysis

3. Co-creation workshop

3.1 Workshop method and description

The 2.2 co-creation workshop was delivered mid-way through the deliverable timeline, in order to engage in dialogue with stakeholders and to use their feedback to inform the theoretical framework, in accordance with the Road-STEAMer WP1 participatory methodology principles. Stakeholders who attended included Road-STEAMer consortium members (*N*=15) and external individuals who could engage in a high-level discussion regarding theoretical frameworks (*N*=15). The majority of the latter group were academics engaged in STEAM practice. As with previous co-creation workshops for the Road-STEAMer project, the workshop was delivered online and, in this instance, the first introductory section was recorded for those who were unable to attend.

The workshop involved the creative use of the digital collaboration tool, Mural, and facilitation questions designed to provoke appropriate dialogue rather than high-speed agreement. In the workshop, participants were introduced to the theoretical framework as detailed above, accompanied with a visualisation created in collaboration with Road-STEAMer partner Politecnico di Milano. Participants were then divided into three breakout groups, facilitated by partners from the University of Exeter, to discuss and seek clarification as to the theoretical framework and the visualisation – in particular, whether they made sense as a way to consolidate a conceptual framework for STEAM practice. As with previous Road-STEAMer co-creation workshops, the process was caveated with the notion that it would not lead to fundamental changes to the theoretical framework, which had been generated using a rigorous analysis process, but that the dialogue was about seeking clarity of understanding.

3.2 Workshop outcomes

Below is a summary of feedback from the three breakout groups:

- It's useful to see them as four parts of the same whole
- Good visualisation. The four categories will need a short explanation though.
- For an academic audience, this framework makes a lot of sense, but for teachers, the framework may not be so useful and practical.
- Curriculum developers might find this framework useful in positioning their work.
- It makes sense as an example for thinking about how to use an underserved group
- The categories are clear - not sure how the criteria were distributed in the categories? e.g., Flow state also seems to fit into the psychological approaches?
- How philosophically exclusive does the framework want to be?

Below (figure 3) is a screenshot of the mural, with definitions of the four approaches, the visualisations and the feedback from the three breakout groups (yellow, blue and green). This image is not intended to show the detail of feedback but rather the format in which it occurred:

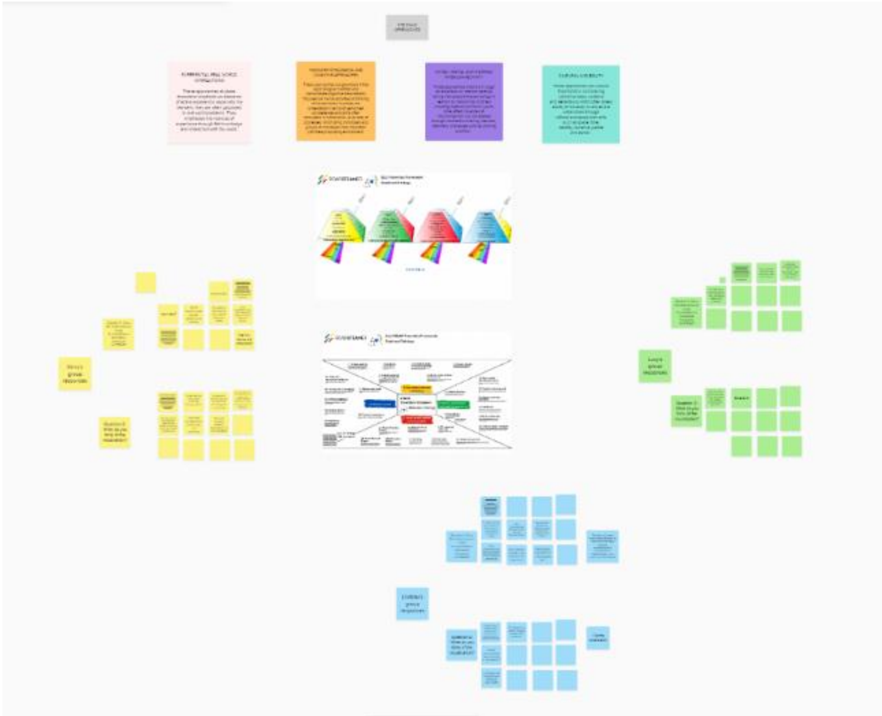


Figure 3 Mural screenshot showing creative digital working space

4. Road-STEAMer Conceptual Framework

4.1 Relational Ontology

At the heart of the Road-STEAMer conceptual framework is the idea that relationality is a foundational concept for STEAM practice. This understanding emerged through the thematic analysis and discussions as it was evident across all of the approaches being analysed, in one way or another. Stemming from an ontological position that foregrounds mutual relations between 'things' (objects or subjects) as fundamental to their existence, this way of viewing the world asserts that "entities are what they are because of their relationships with other entities" (Spyrou, 2022). Taking this idea into the field of education, and drawing on the literature at hand, our conceptual framework is therefore rooted in the principle that there can be 'no education without relation' (Bingham & Sidorkin, 2004), extending this from the arguments in Bingham and Sidorkin's edited volume focused on human relations to a broader understanding of relationality and its role in education. From this starting point, the Road-STEAMer conceptual framework considers the fundamental importance of relations between humans (e.g., teacher-student) in education but also the importance of relations between disciplines, between settings, between humans and the 'real world' with which they interact, and so on. As part of our co-creation and dialoguing process, this conceptualisation of relationality at the heart of STEAM education was identified as underpinning the framework prior to the main analysis.

Having a relational ontology underpinning our conceptualisation of STEAM suggests that the framework developed to guide our study of STEAM practices and policy, and potentially guidance for practice, needs to focus on how relations between different elements of STEAM practice create and affect the practices themselves. However, in the analytical process described above, the range of conceptual and theoretical approaches identified in the literature and grouped under the four main thematic 'umbrellas' may not themselves have been conducted with the same relational conceptualisation. This means that within Road-STEAMer, when using the conceptual framework to guide interrogation of practice and policy, or guide the development of new practices and policies, it will be important to consider what the theoretical approach does and how its application acts in the world *with a relational perspective* in mind.

To support this stance and the way in which relationality is a foundational concept within the Road-STEAMer framework, we have developed a visual (Figure 4) to really highlight the network of relations between different actors within STEAM policy and practice**.**

Figure 4 Relational ontology symbol

4.2 Four approaches

Figures 5 and 6 offer visualisations of the Road-STEAMer conceptual framework pyramid.

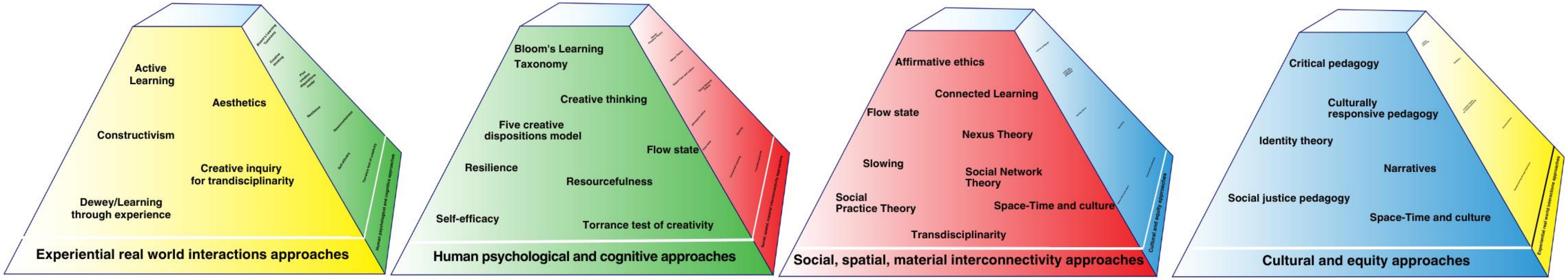
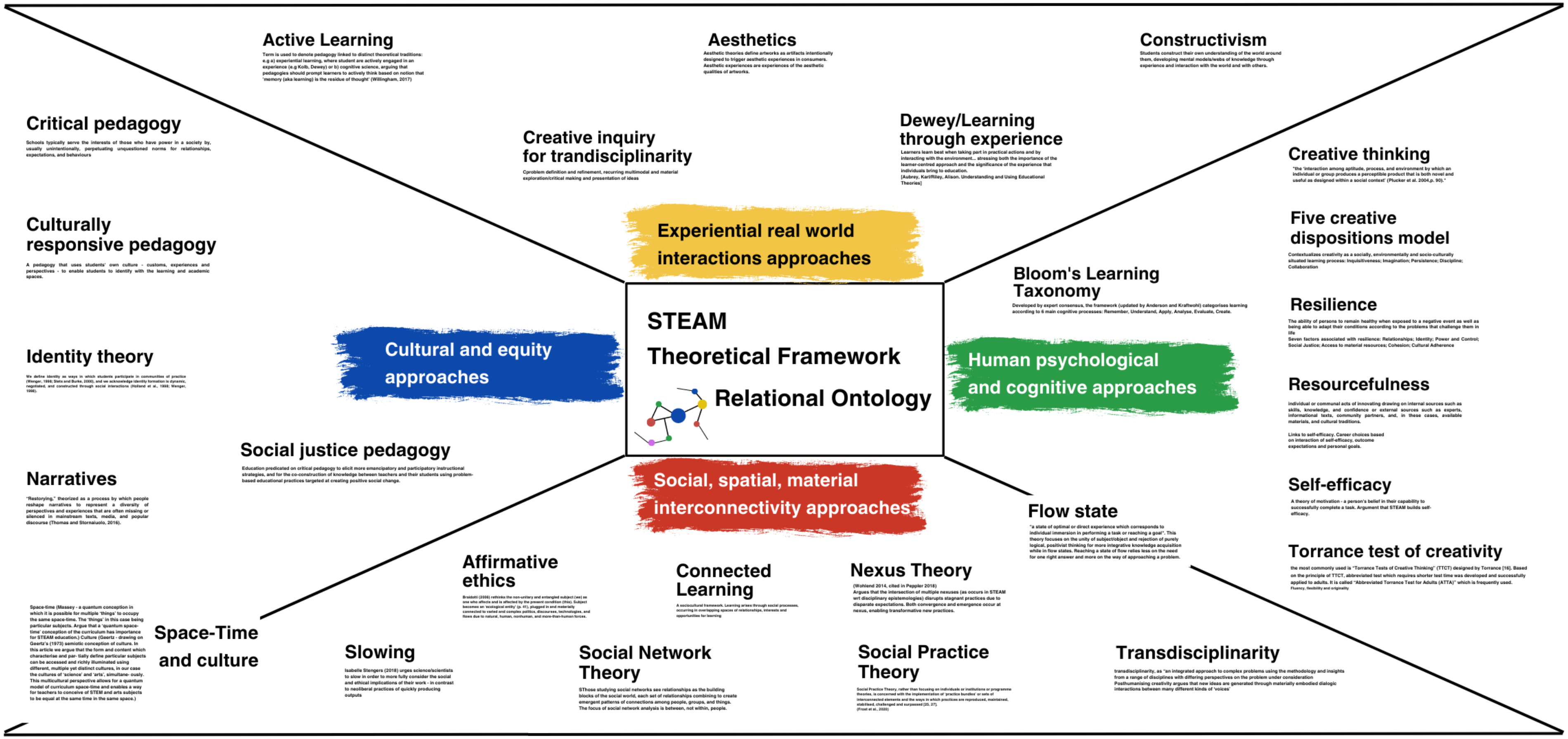


Figure 5 The Road-STEAMer conceptual framework visual



** We consider this visualisation to be an evolving tool, and as such we ask that users consider the following:*

- *The theories noted here are an indicative, rather than exhaustive list of those which may be used to investigate STEAM practice*

Figure 6 The Road-STEAMer conceptual framework pyramid aerial visual

Within the relational ontology described above, the deliverable D2.2 analytic process surfaced four different but connected over-arching approaches: experiential real-world approaches; human psychological and cognitive approaches; social, spatial and material interconnectivity approaches; and cultural and equity approaches. Figure 5 shows a single pyramid with four different coloured faces to represent the four different approaches. The pyramid is used as a visual metaphor to show that whilst each approach has distinct characteristics it is still related to the other approaches via the relational ontology. Figure 6 shows the pyramid from an aerial view demonstrating the relational ontology as the connection between all four approaches. Figure 6 also shows that some of the theories sit within more than one of the four approaches and we emphasise that there is more fluidity in the relationship between the approaches than it is perhaps possible to demonstrate in visualisations of this kind. For those of a philosophical bent it will be noticeable that the four approaches broadly speaking are grounded in different paradigmatic approaches which draw across educational, philosophical and social sciences theory and research; these will be further explained in sections 4.2.1 - 4.2.4.

Going forward, it should be noted that is not intended that these are the only four approaches possible for STEAM education; these have been generated by the particular foci of the Road-STEAMer project. This conceptual framework may well develop across and beyond the lifecourse of the Road-STEAMer project given the fast-moving pace of current paradigms such as posthumanism and the advent of Artificial Intelligence (AI) and its impacts on education practice and theory. This may perhaps lead to the inclusion of more new approaches or the embellishment of the four existing ones.

Next, each approach is defined and explained. The theories which have been applied to and have shaped understanding of STEAM within each of the four approaches are also detailed in the sub-sections below. The theories within each approach are detailed in alphabetical order and there is no hierarchy intended between them within each of the approaches' descriptions.

4.2.1 Experiential real-world interactions approach

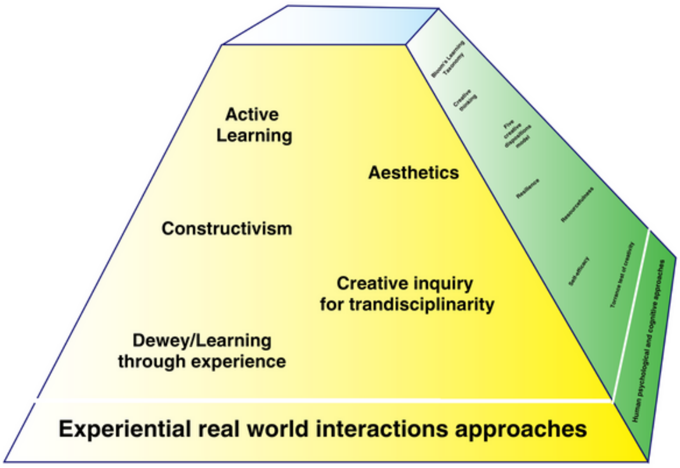


Figure 7 Experiential real world interactions approaches

These approaches all place theoretical emphasis on elements of active experience, especially the learners'; they are often grounded in real world problems. They emphasise the nuances of experience through felt knowledge and interaction with the world. The theories or concepts organised in this group (along with citations of the key references) were:

Active Learning (Caratozzolo et al., 2021)

Active learning is a pedagogy linked to distinct theoretical traditions: e.g., a) experiential learning, where students are actively engaged in an experience (e.g., Kolb, Dewey) or b) cognitive science, arguing that pedagogies should prompt learners to actively think based on the notion that 'memory (aka learning) is the residue of thought' (Willingham, 2009, p. 79). In this example, Caratozzolo et al. (2021) employ this approach to understand how to foster digital literacy in University level engineering education within a STEAM setting.

Aesthetics (Mehta et al., 2019)

Aesthetics Education has been defined as "an intentional undertaking designed to nurture appreciative, reflective, cultural, participatory engagements with the arts by enabling learners to notice what is there to be noticed, and to lend works of art their lives in such a way that they can achieve them as variously meaningful" (Greene, 2001, p. 6). Mehta et al. (2019) use a ‘rhetoric’ of aesthetics to be incorporated in teaching for integrating the aesthetic in STEM learning and to guide teacher professional development for STEM educators.

Constructivism (Domenici, 2022)

Constructivism is a theory of learning which claims that “(human) knowledge is acquired through a process of active construction”. Specifically, constructivist claims of learning can be summarised as follows: “(1) Learning is an active process. (2) Knowledge is constructed, rather than innate, or passively absorbed. (3) Knowledge is invented not discovered. (4a) All knowledge is personal and idiosyncratic. (4b) All knowledge is socially constructed. (5) Learning is essentially a process of making sense of the world. (6) Effective learning requires meaningful, open-ended, challenging problems for the learner to solve” (Fox, 2001, p. 24). Domenici (2022) uses constructivism as part of professional development for teachers on a STEAM Project-based Learning Methodology developed in a science museum.

Creative inquiry for transdisciplinarity (Costantino, 2017)

This approach is articulated by Costantino (2017) themselves and they see creative inquiry as an iterative process, focused on problem definition and refinement, recurring multimodal and material exploration/critical making and presentation of ideas with in-process critique occurring at multiple points in the inquiry process and exhibition as a point in the cycle that may also generate a reframing of the problem and stimulate further inquiry. Costantino (2017) uses this model to investigate transdisciplinary curricula which bring together art and design with STEM across secondary and tertiary education.

Dewey/Learning Through Experience (Stroud & Baines, 2019)

John Dewey emphasised the joining of education and experience for learners to construct knowledge, shifting away from traditional education settings where classroom contexts were unconnected to the contexts of the content students were learning. According to Stroud and Baines (2019), “Dewey (1933) developed a procedure to support the construction of knowledge within a particular experience: 1. Observation of surrounding conditions 2. Knowledge of what has happened in similar situations in the past 3. Judgment which puts together what is observed to see what they signify” (p. 3). Stroud and Baines (2019) use this as a principle of Inquiry-based learning, integrating images and the arts into STEM to make STEAM learning.

4.2.2 Human psychological and cognitive approaches

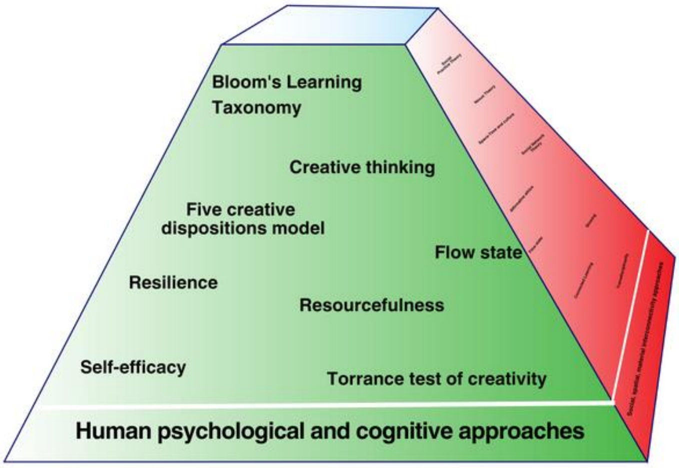


Figure 8 Human psychological and cognitive approaches

These approaches are grounded in the psychological tradition and demonstrate cognitive theorisations (focused on mental activities or thinking of varied kinds). Nuances are understood in terms of self-driven competences and skills often articulated in frameworks, or as sets of processes, which bring individuals and groups of individuals into interaction with the surrounding environment. The theories or concepts organised in this group (along with citations of the key references) were:

Bloom's Learning Taxonomy (Del Valle-Morales et al., 2020)

Developed by expert consensus, Bloom’s Learning Taxonomy (updated by Anderson and Kraftwohl) is “a framework for classifying statements of what we expect or intend students to learn as a result of instruction” (Krathwohl, 2002, p. 212). The framework categorises learning according to 6 main cognitive processes: Remember, Understand, Apply, Analyse, Evaluate, Create. In their study, Del Valle-Morales et al. use the taxonomy to create long-term, meaningful learning experiences for children to motivate them to pursue a STEAM career (Del Valle-Morales et al., 2020).

Creative Thinking (Chen & Lo, 2019)

Creative Thinking has been defined as the "interaction among aptitude, process, and environment by which an individual or group produces a perceptible product that is both novel and useful as designed within a social context" (Plucker et al., 2004, p. 90). Students applying creative thinking can use their subjective perspective to consider 'diverse concepts' which can lead to innovation (Chen & Lo, 2019, p. 76). Chen and Lo (2019) apply Creative Thinking through a Human-Centred Design System by designing an innovative musical instrument.

Five Creative Dispositions Model (Harris & de Bruin, 2017)

The Five Creative Dispositions Model contextualizes creativity as a "socially, environmentally and socio-culturally situated learning process", consisting of five core dispositions: Inquisitiveness; Imagination; Persistence; Discipline; Collaboration (Harris & de Bruin, 2017, p. 158). In their paper, Harris and de Bruin (2017) use this theoretical model to investigate teacher and student understandings of creativity across disciplines as part of an international study of secondary schools in Australia, USA, Canada and Singapore.

Flow state (Dredd et al., 2021)

Flow state is "a state of optimal or direct experience which corresponds to individual immersion in performing a task or reaching a goal" (Dredd et al., 2021, p. 1). This theory focuses on the unity of subject/object and rejection of purely logical, positivist thinking for more integrative knowledge acquisition while in flow states. Reaching a state of flow relies less on the need for one right answer and more on the way of approaching a problem. Dredd et al. (2021) use flow state to compare how STEAM students and electrical engineering students experience their coursework.

Resilience (Del Valle-Morales et al., 2020)

Resilience is defined as "the ability of persons to remain healthy when exposed to a negative event as well as being able to adapt their conditions according to the problems that challenge them in life" (Del Valle-Morales et al., 2020, p. 141). Seven factors commonly associated with resilience are: Relationships; Identity; Power and Control; Social Justice; Access to material resources; Cohesion; Cultural Adherence. Del Valle-Morales et al. (2020) investigated whether STEAM education could be used to develop resilience skills in K-12 students.

Resourcefulness (Avendano-Uribe et al., 2022)

Resourcefulness is defined as “individual or communal acts of innovation, drawing on internal sources such as skills, knowledge, and confidence or external sources such as experts, informational texts, community partners, and, in these cases, available materials, and cultural traditions” (Avendano-Uribe et al., 2022, p. 3). The authors of this study Avendano-Uribe et al. (2022) found resourcefulness as one of three characteristics which emerged in makerspaces situated in rural Colombia.

Self-efficacy (Boice et al., 2021; Full et al., 2021)

Self-efficacy is defined as an individual’s expectations of eventual success when performing specific activities (Bandura, 1977). Perceived self-efficacy has been argued to affect people’s “choice of activities and behavioural settings, how much effort they spend, and how long they will persist in the face of obstacles and aversive experiences” (Bandura & Adams, 1977, p. 288). As such, it is a popular construct to understand engagement/disengagement and persistence in STEM, and now STEAM. This is evidenced in studies such as Boice et al. (2021), who investigated how STEAM training influenced teachers’ perceived perceptions and practices related to self-efficacy, and Full et al. (2021), who developed STEAM enrichment activities for undergraduate students.

Torrance tests of creativity (Chang et al., 2019)

“Torrance Tests of Creative Thinking” is an alternative framework for creativity (see Five Creative Dispositions Model above) and is often considered to be the most widely used test of creativity. Torrance (1966, p. 6) defined creativity as “a process of becoming sensitive to problems, deficiencies, gaps in knowledge, missing elements, disharmonies, and soon; identifying the difficulty; searching for solutions, making guesses, or formulating hypotheses about the deficiencies: testing and retesting these hypotheses and possibly modifying and retesting them; and finally communicating the results”. The tests Torrance developed measured four components: fluency, flexibility, originality and elaboration. In their study, Chang et al. (2019) used the tests to measure the influence of interactive art of visual music on the creativity of science and engineering students.

4.2.3 Social, spatial and material interconnectivity approaches

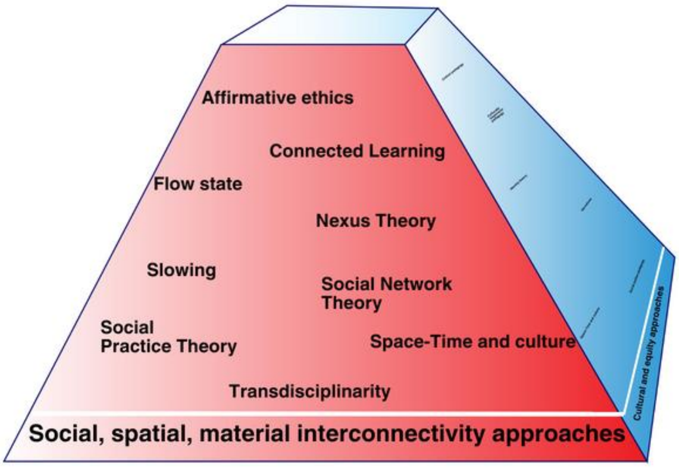


Figure 9 Social, spatial and material interconnectivity approaches

These approaches theorise through an emphasis on interconnectivity considering human beings in relation to many kinds of others including material elements, space, time, affect. Nuances of interconnection are considered through connection-making, nexuses, networks, processes such as slowing and flow. The theories or concepts organised in this group (along with citations of the key references) were:

Affirmative Ethics (Guyotte, 2020)

Affirmative ethics as advocated by Braidotti (2006) takes a relational approach in which the subject (we) is entangled in a social and material present: an 'ecological entity' that is materially connected to human and non-human others and through the entangled relationships and affects and is affected by the present. From this relational perspective, ethics becomes an ongoing action in the present world in which the subject is entangled, oriented towards an as-yet-unknown future. Guyotte (2020) argues that this is an important conceptual position for

STEAM education in which relational and entangled entities are acting in the world with an affirmative ethical orientation to the future.

Connected Learning (Bass et al., 2016)

Connected Learning advocates a sociocultural approach to learning in which young people “pursue a personal interest or passion with the support of friends or caring adults and is in turn able to link this learning and interest to academic achievement, career success or civic engagement” (Ito et al., 2013, p. 42). It seeks to build communities and collective capacities for learning and opportunity, particularly for disadvantaged youth. Bass et al. (2016) operationalised connected learning in their project-based media production programme for underrepresented minority young people to prepare them for higher education and technology careers.

Flow state (Dredd et al., 2021)

Flow state is "a state of optimal or direct experience which corresponds to individual immersion in performing a task or reaching a goal" (Dredd et al., 2021, p. 1). This theory focuses on the unity of subject/object and rejection of purely logical, positivist thinking for more integrative knowledge acquisition while in flow states. Reaching a state of flow relies less on the need for one right answer and more on the way of approaching a problem. Dredd et al. (2021) use flow state to compare how STEAM students and electrical engineering students experience their coursework.

Nexus Theory (Peppler & Wohlwend, 2018)

Nexus theory argues that the intersection of multiple nexuses (as occurs in STEAM with respect to disciplinary epistemologies) disrupts stagnant practices due to disparate expectations. Both convergence and emergence occur at nexus, enabling transformative new practices (Peppler & Wohlwend, 2018; Wohlwend, 2013). Peppler and Wohlwend (2018) advocate for the use of Nexus Theory to create transformative learning experiences in STEAM activities.

Slowing (Guyotte, 2020)

Isabelle Stengers (2018) urges science/scientists to slow in order to more fully consider the social and ethical implications of their work - in contrast to neoliberal practices of quickly producing outputs. In their article, Guyotte (2020) suggest that slow(ing) can be used as an approach to STEAM education because it acknowledges the individual's situatedness and allows them to notice how they are materially implicated in the natural world – and thus moving away from anthropocentric perspectives.

Social Network Theory (Boice et al., 2021)

Social Network Theory sees "relationships as the building blocks of the social world, each set of relationships combining to create emergent patterns of connections among people, groups, and things. The focus of social network analysis is between, not within, people"(Hansen et al., 2011, p. 32). Boice et al. (2021) use social network analysis in their study to measure changes in teacher collaboration networks following participation in a collaborative STEAM teacher training programme.

Social Practice Theory (Quigley et al., 2019)

Social Practice Theory, rather than focusing on individuals or institutions or programme theories, is concerned with the implementation of 'practice bundles' or sets of interconnected elements and the ways in which practices are reproduced, maintained, stabilised, challenged and surpassed (Frost et al., 2020). Quigley et al. (2019) use social practice theory to distinguish between STEM and STEAM, identifying that the key difference in the transdisciplinary approach used within STEAM practice.

Space-time and Culture (Davies & Trowsdale, 2021)

Drawing on Geertz's (1973) semiotic conception of culture, Davies and Trowsdale (2021) suggest that subjects are characterised and partially defined by their form and content, and that these can be explored and understood in STEAM contexts through a 'multicultural' lens which simultaneously enables understanding of disciplinary cultures through their interaction. Connected to this, Davies and Trowsdale draw on the quantum conception of space-time as a means of thinking about this multicultural perspective, arguing that the existence of disciplinary cultures in the same space-time is a helpful conceptualisation for teachers to view STEM and Arts subjects to be equal at the same time, in the same space.

Transdisciplinarity / Creativity through Spatiality / Materiality beyond the human (Chappell et al., in press)

Transdisciplinarity, as “an integrated approach to complex problems using the methodology and insights from a range of disciplines with differing perspectives on the problem under consideration” (Benatar, 2000). In this article, Chappell et al. (in press) argue for posthumanising creativity as generating new ideas in STEAM education through materially embodied dialogic interactions between many different kinds of ‘voices’.

4.2.4 Cultural and Equity approaches

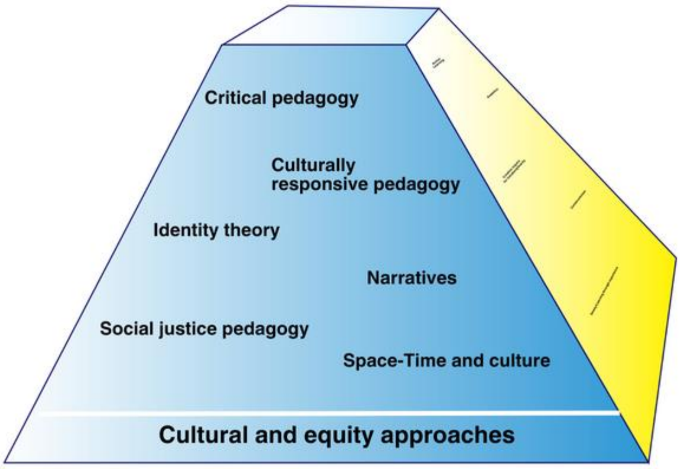


Figure 10 Cultural and Equity approaches

These approaches use cultural theorisations (considering collective ideas, customs and behaviours) which often stress equity of inclusion. Nuances are understood through cultural processes/elements such as space, time, identity, narrative, justice and power. The theories or concepts organised in this group (along with citations of the key references) were:

Critical Pedagogy (Chung & Li, 2021; Fletcher & Hernandez-Gantes, 2021; Kiyani et al., 2020)

Critical Pedagogy "sees education as a tool for empowerment, a place where learners develop the knowledge and skills they need to undo oppressive structures and achieve liberation" (Saunders & Wong, 2020, p. 76). The capacity of STEAM practice to drive social change through critical pedagogy education is investigated in multiple studies, including Chung and Li (2021); Fletcher and Hernandez-Gantes (2021); and Kiyani et al. (2020).

Culturally Responsive Pedagogy (DeVito et al., 2020; Kant et al., 2018; Rao et al., 2021)

Culturally Responsive education is defined as "an educator's academic partnership with students anchored in commitment, respect, integrity, and honoring diversity" (DeVito et al., 2020, p. 3). It is a student-centred approach to teaching that "includes cultural references and recognizes the importance of students' cultural backgrounds and experiences in all aspects of learning" (Samuels, 2018), enabling students to identify with learning and academic spaces. In their studies, DeVito et al. (2020), Kant et al. (2018) and Rao et al. (2021) use culturally responsive pedagogies to facilitate social justice for minoritised students through STEAM teaching.

Narratives (Avendano-Uribe et al., 2022)

Narratives, or "Restorying," is theorized as a process by which people reshape narratives to represent a diversity of perspectives and experiences that are often missing or silenced in mainstream texts, media, and popular discourse (Thomas & Stornaiuolo, 2016). As with resourcefulness (*see above*), Avendano-Uribe et al. (2022) identified narratives as a characteristic which emerged from makerspaces situated in rural Colombia.

Identity Theory (Avendano-Uribe et al., 2022; Claville et al., 2019; Full et al., 2021)

Identity is defined as ways in which students participate in communities of practice (Wenger, 1998; Stets and Burke, 2000). Identity formation is argued to be dynamic, negotiated, and constructed through social interactions (Holland et al., 1998; Wenger, 1998). Identity theories are often used to explore engagement/disengagement and persistence in STEM, especially for those from underrepresented groups, and are used in Avendano-Uribe et al. (2022); Claville et al. (2019) and Full et al. (2021) to similar effect in STEAM context.

Social Justice Pedagogy (Fletcher & Hernandez-Gantes, 2021)

Social Justice Pedagogy is “education predicated on critical pedagogy to elicit more emancipatory and participatory instructional strategies, and for the co-construction of knowledge between teachers and their students using problem-based educational practices targeted at creating positive social change” (Fletcher & Hernandez-Gantes, 2021, p. 359). In their study, Fletcher and Hernandez-Gantes (2021) used social justice pedagogy to investigate school administrator and teachers’ STEAM pedagogical practices with minoritised students.

Space-Time and Culture (Davies & Trowsdale, 2021)

Drawing on Geertz’s (1973) semiotic conception of culture, Davies and Trowsdale (2021) suggest that subjects are characterised and partially defined by their form and content, and that these can be explored and understood in STEAM contexts through a ‘multicultural’ lens which simultaneously enables understanding of disciplinary cultures through their interaction. Connected to this, Davies and Trowsdale draw on the quantum conception of space-time as a means of thinking about this multicultural perspective, arguing that the existence of disciplinary cultures in the same space-time is a helpful conceptualisation for teachers to view STEM and Arts subjects to be equal at the same time, in the same space.

4.3 The four approaches in relationship with the Road-STEAMer Criteria

Having articulated the four approaches and their defining characteristics, it is now necessary to connect the conceptual framework as presented in this deliverable with the core Road-STEAMer criteria developed in deliverable 4.1 (D4.1). These Road-STEAMer project criteria will be used to map and analyse STEAM practices in Europe, and as such provide the practical tools to carry out the Road-STEAMer project. By coupling the criteria with the conceptual framework here it increases the rigour with which the Road-STEAMer project can claim the efficacy of both the criteria and the mapping as both deliverable D4.1 and deliverable D2.2 are grounded in reviews of literature and co-creation workshops.

To create the criteria in deliverable D4.1, 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 Road-STEAMer focus areas. This led to the identification of 6 key criteria and 1 underlying principle argued to be characteristic of successful STEAM practice within the Road-STEAMer foci. Equity was identified as the one underlying principle and value that supports all STEAM practice and is therefore an all-pervading criteria. The key criteria were identified as Collaboration, Disciplinary inter-relationships, Thinking-making-doing, Creativity, Real-world connection and Inclusion/ Personalisation/ Empowerment.

In order to strengthen the use of the Road-STEAMer criteria by demonstrating them in action in relation to the four approaches within the conceptual framework, each of the four approaches are articulated below showing how it makes the criteria manifest – as the prominence of each criteria differs depending which approach is being used. These are visualised in Figure 11, which shows each approach pyramid with a shaft of light shot through it which then diffracts out of the front of the pyramid. The metaphor means that each approach creates a different pattern of inter-relationship of the criteria in front of the pyramid, visualised through the different layout of the criteria on the rainbow in front of each pyramid.

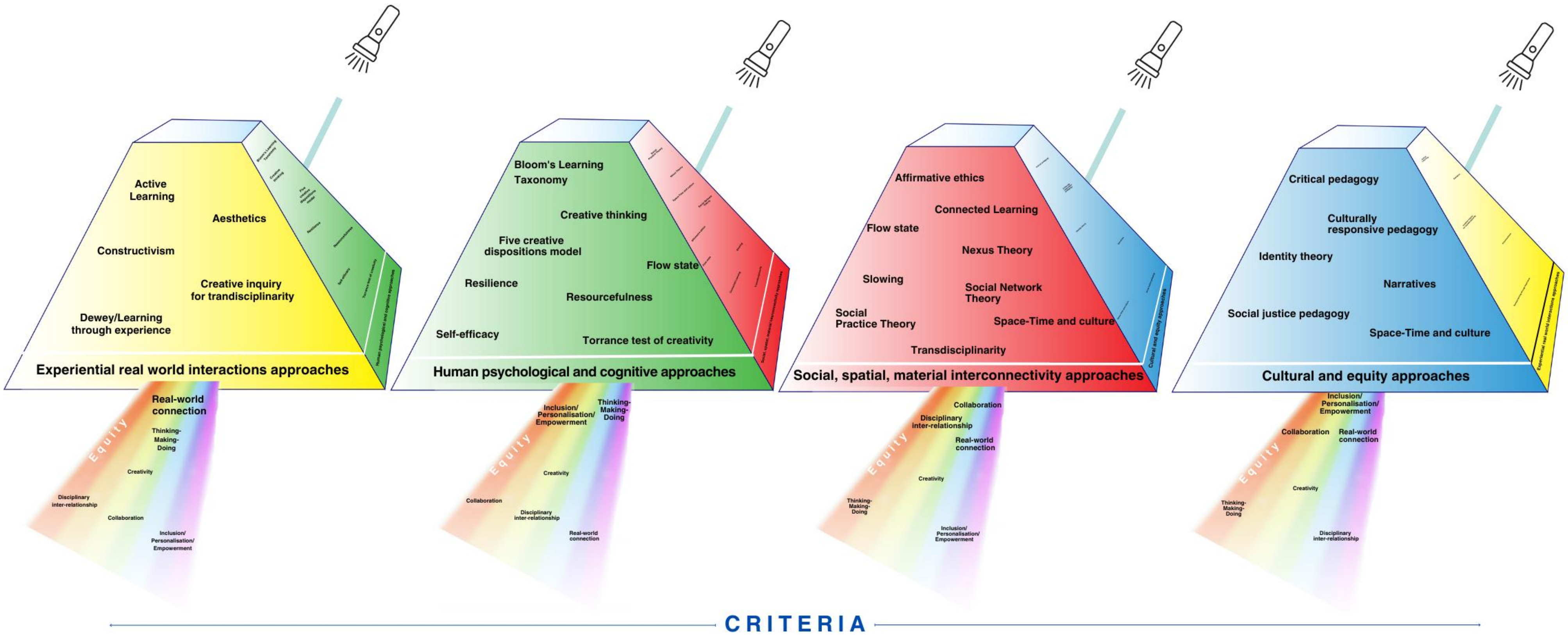


Figure 11 Each approach's pyramid diffracting the criteria showing a different manifestation of the criteria in relation to that approach

In the next section, how each approach manifests the criteria differently is explained, with an illustrative example. It is important to note that these examples have been developed by taking an existing practice and using the conceptual framework to explain a theoretical stance that connects to the practice. The examples have not been developed as practices using the Road-STEAMer conceptual framework as a guide.

4.3.1 Experiential real-world interaction approaches and the criteria

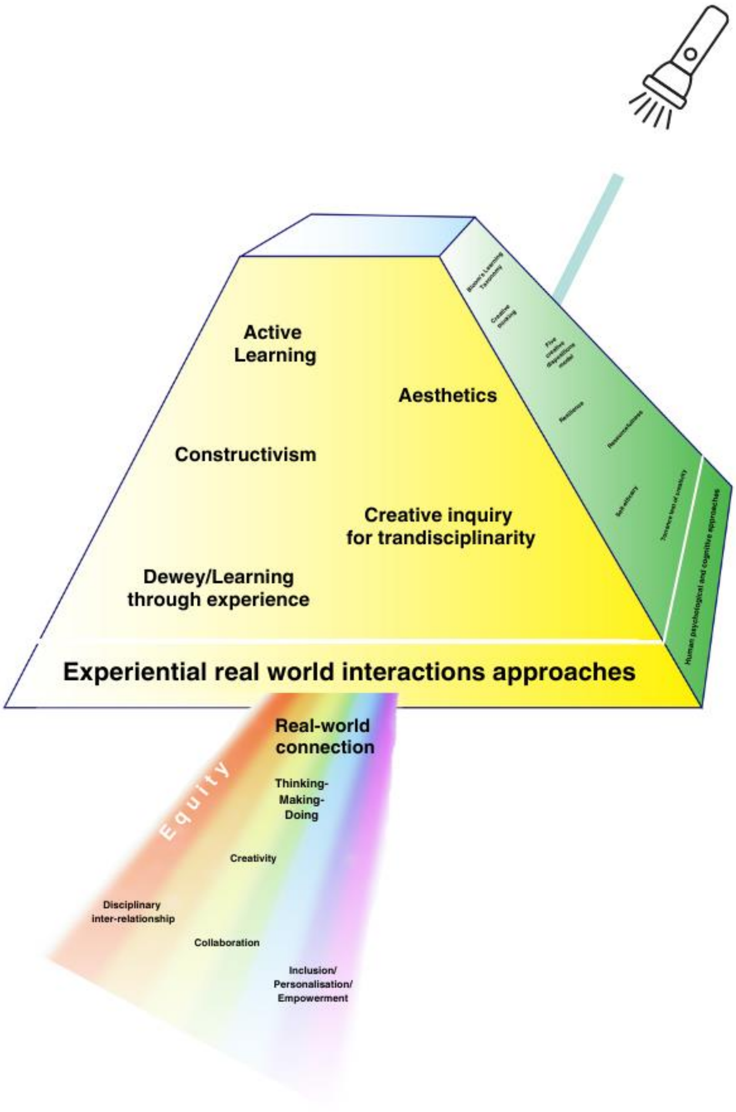


Figure 12 Experiential real-world interaction approaches and how they manifest the criteria

In these approaches theoretical emphasis is placed on elements of active experience, especially the learners'; they are often grounded in real world problems. They emphasise the nuances of experience through felt knowledge and interaction with the world. It is therefore perhaps not surprising that when considered through these conceptual approaches, the **Real-world Connections** criteria manifests most strongly. Only slightly less dominant is the criteria of **Thinking-making-doing** as this focuses on the practical activities involved in STEAM that make it relevant to real-world problems. Slightly less dominant is the supporting criteria of **Creativity –** whether conceived of as creative thinking or as a process/product developmental cycle. Finally, for this conceptual approach **Disciplinary Inter-relationship**, **Collaboration** and **Inclusion/personalisation/empowerment** in service to real-world connections and interactions. This all occurs through equitable practices grounded in a relational approach to the world.

This manifestation of the criteria through the Real-world Interaction Approaches is brought to life in the example that follows:

Example 1: Laughing for Change: Experiencing Climate Reality Through Stand-Up Comedy
As part of the EU Next Step project (www.the-next-step.eu), this STEAM activity empowers students to use stand-up comedy to convey the complexities of climate change. They delve into the science, exploring the causes and effects of climate change, use digital resources to gather and analyse data, and then create stand-up routines using these facts. Students learn about the art and craft of comedy writing as they craft their routines, using humour to highlight the absurdities and ironies of our collective response to climate change. Performances demonstrate students' understanding of both climate change and their ability to communicate complex ideas both effectively and with humour. The initiative was deeply anchored in a commitment to ***experiential, real-world interactions****. The project was structured to use real data and statistics as part of a collaborative activity designed to address challenges in ways that wove* ***pupils' personal experiences and perspectives*** *into their routines: real world connection was established through grounding the routines in students' own lives and interests to make climate change, which can be a daunting or abstract topic, relatable to students. The* ***experiential real-world interaction approach*** *foregrounds the criteria* ***collaboration, disciplinary inter-relationships, thinking-making-doing, creativity, real-world***

connection, inclusion, personalisation and empowerment. *The project was designed to ensure students' voices were central to the design of activities, and focused on inclusion of young people facing challenging personal situations and with little enthusiasm for traditional education and thus draws on real-world experiences to include and empower young people. Collaboration between teachers and students was crucial. Disciplinary inter-relationships are drawn upon through connecting the science of climate change with the art of stand-up comedy and comedy writing, which is also connected through to creativity. Thinking-making-doing in this project is closely linked to real-world interaction approaches as the project draws on real-world experience and then acts to make a difference in the world through the production and performance of a routine.*

4.3.2 Human psychological and cognitive approaches and the criteria

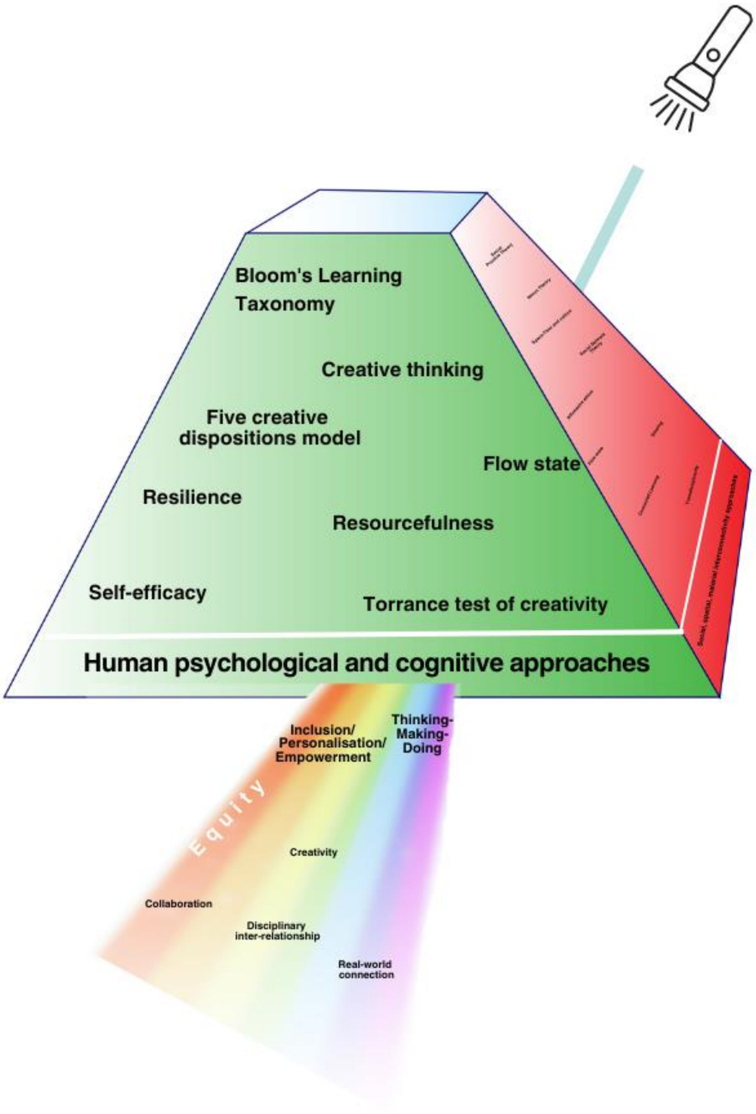


Figure 13 Human psychological and cognitive approaches and how they manifest the criteria

In these approaches theorisations are focused on mental activities or thinking of varied kinds grounded in the psychological and cognitive research traditions. Nuances are understood in terms of self-driven competences and skills often articulated in frameworks, or as sets of processes, which bring individuals and groups of individuals into interaction with the surrounding environment. This means that the dominant criteria here are **Thinking-making-doing** and **Inclusion/personalisation/empowerment**. With a focus on the human as driving

STEAM activities through different cognitive tactics and strategies, the focus on individual empowerment and inclusion rises to the fore, often through the personalisation of activities to different individuals' preferred ways of working; hence the dominant focus here too on Thinking-making-doing. Each individual drives their own Thinking-making-doing through the cognitive skills available to them or being developed through the STEAM learning activity. As with other approaches this is supported by **Creativity**, quite often conceived as creative thinking skills in this approach. In background facilitation roles for this approach are **Disciplinary Inter-relationship**, **Collaboration** and **Real-world connections**. These latter criteria are still very relevant but they support individuals' personalised learning journeys rather than dominating how STEAM manifests here. This all occurs through equitable practices grounded in a relational approach to the world.

This manifestation of the criteria through the Human psychological and cognitive approaches is brought to life in the example that follows:

Example 2: Learning Science Through Theatre

Learning Science through Theatre (http://lstt.eu/) is a STEAM practice in which students learn about both Science and Arts together as they develop a theatre performance of scientific ideas. It aims to connect science and arts, and also connects schools with the local community and the research community, by asking students to produce a production that dramatizes scientific ideas based on their school curriculum whilst addressing a solution to issues of interest to the community around the school. Using the STEAM IDEAS' Square (SIS), based on Design Thinking, students FEEL societal needs, IMAGINE novel solutions for the future, CREATE these within the school and SHARE them with the community. Learning Science through Theatre can be conceptualised as a STEAM practice based on ***Human Psychological and Cognitive Approaches:*** *With a focus on making the school a community hub in which problems facing the community can be explored using scientific concepts with a creative approach to finding solutions and communicating them via performance, pupils are required to use and develop some key skills such as* ***resourcefulness and resilience****. Project may be designed to develop and draw on* ***creative dispositions*** *such as* Inquisitiveness; Imagination; Persistence; Discipline; Collaboration. *In addition, students will be required to use* ***higher order thinking skills*** *in order to analyse, evaluate and create responses to issues raised.*

Using human psychological or cognitive approaches foregrounds criteria of ***thinking-making-doing*** *and* ***inclusion, personalisation and empowerment.*** *In LSTT, this is very clearly drawn out in the material creation of a performance based on understanding of key ideas in science, theatre performance and about the local community, with personalisation and empowerment enabling and enabled by the development of the key skills described above. Learning Science through Theatre is associated with the CREATIONS EU Project, the SciCulture/D EU project, the OSOS EU Project, and NEXT STEP EU Project (http://creations-project.eu/; https://scicultured.eu/; https://www.openschools.eu/; https://www.the-next-step.eu/).*

4.3.3 Social, spatial and material interconnectivity approaches and the criteria

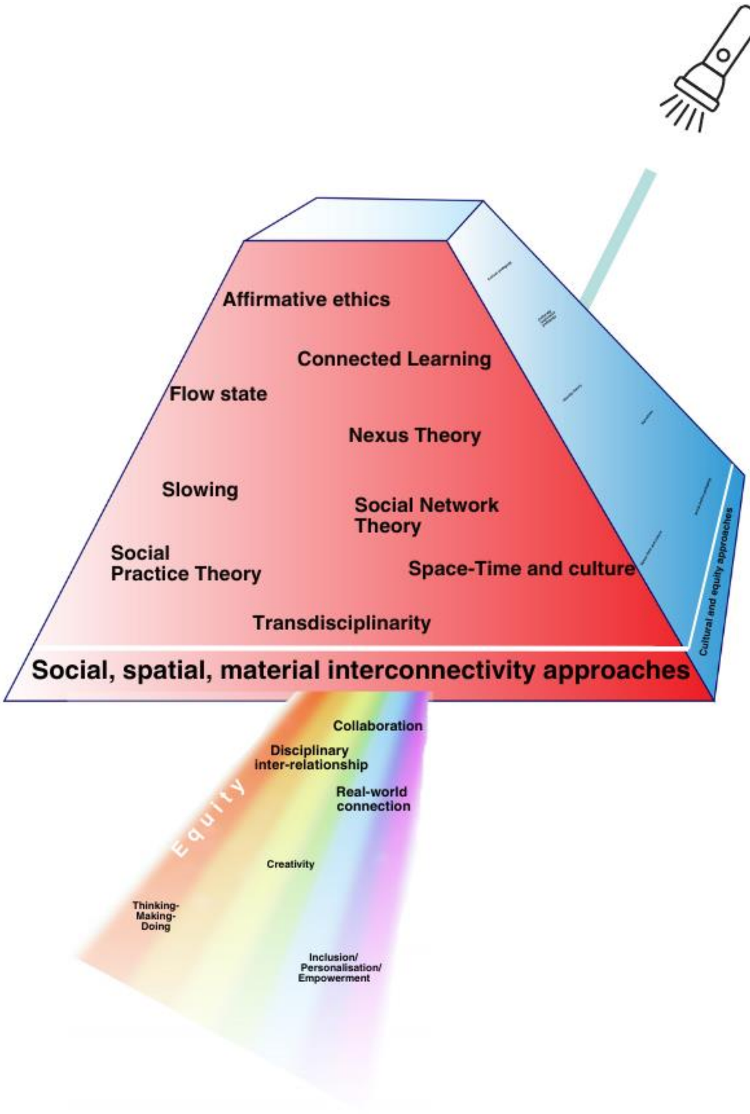


Figure 14 Social, spatial and material interconnectivity approaches and how they manifest the criteria

In these approaches there is an emphasis on interconnectivity considering human beings in relation to many kinds of others including material elements, space, time, affect. Nuances of interconnection are considered through connection-making, nexuses, networks, processes such as slowing and flow. This means that the dominant criteria that manifest are **Real-World Connections**, **Collaboration** and **Disciplinary Inter-relationship**. This is because the focus in STEAM activities conceptualised in this way is often on the real-world problems in hand, much less on the humans and much more on elements such as environment and its constituent factors. Collaboration with other humans but also with elements of the environment and technology becomes key, as does how the disciplines interact differently when humans are decentralised in these approaches. As with the other approaches, the **Creativity** criteria is in a strong supporting role here, this time conceived in more collaborative, dispersed or posthuman ways, and often thought of as dialogic. In background facilitation roles in these approaches are **Thinking-making-doing** and **Inclusion/personalisation/empowerment**. This is because the first two support individual humans in their activities which are in a subservient role here. This all occurs through equitable practices grounded in a relational approach to the world.

This manifestation of the criteria through the Social, spatial and material interconnectivity approaches is brought to life in the example that follows:

Example 3: The Ozone Game

*Part of the STEAM School Malta initiative (https://steamsummerschool.eu), the Ozone Game is a STEAM Practice aimed at primary and secondary students who learn about the role of the ozone layer in the atmosphere, the CFC issue and how the ozone layer was repaired. Using a 'game' approach, students use physical materials such as marbles, painted signs and physical role play to understand and 'perform' what is happening in a play about the Ozone layer. The **physical and material spaces** are crucial to the effectiveness of this activity in parallel with social element of **collaboration**, facilitation and dialogue. The social, spatial and material approach includes theoretical perspectives such as 'Slowing' and which supports taking the time to teach using these material and collaborative STEAM approaches and '**transdisciplinarity**' in which both sciences and arts are using together, including in material and social collaborative spaces, to address a key issue such as the environmental challenge at the heart of this STEAM practice. The criteria foregrounded with this approach are the **real-world connection**, **transdisciplinarity** and **collaboration**, which are all clearly present at the heart of this STEAM practice. Alongside the spatial, material and social theoretical approaches, this practice also draws on a theoretical stance of **active learning** within this collaborative and material space which also connects into the real-world connection criteria* *and exemplifies how there can at times be bridges between the thematised theoretical approaches outlined in this deliverable.*

Figure 15 Children in Malta playing the 'Ozone Game'. Picture credit: University of Malta

4.3.4 Cultural and Equity approaches and the criteria

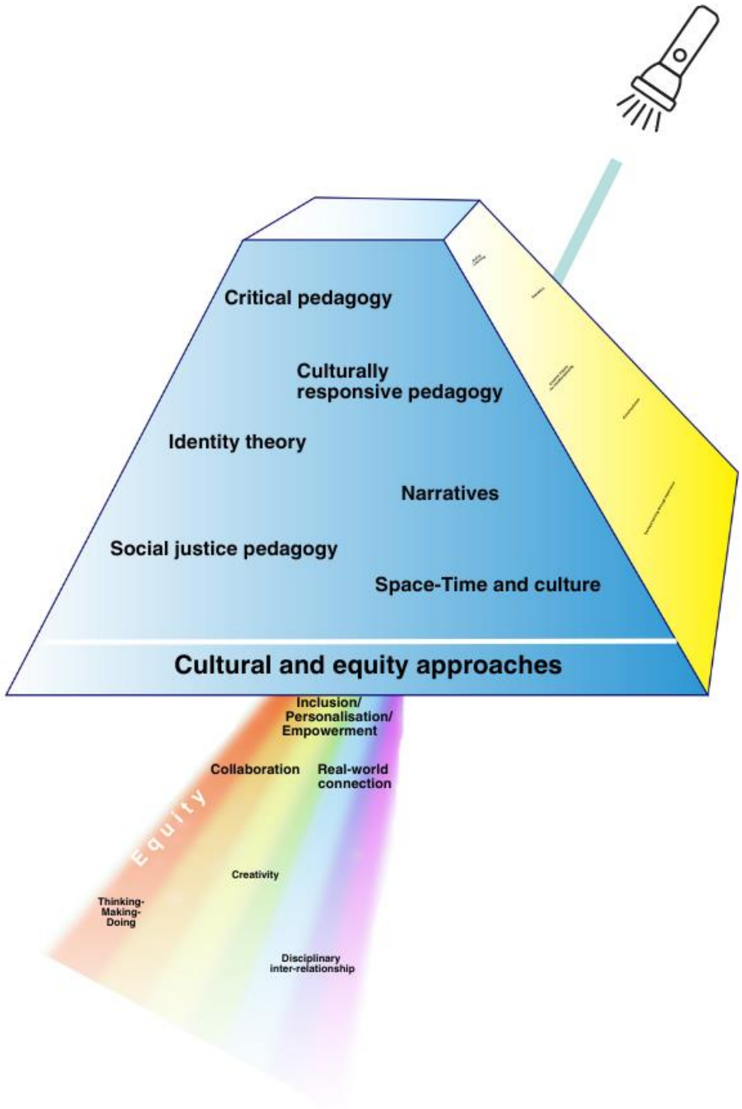


Figure 16 Cultural and equity approaches and how they manifest the criteria

In these approaches cultural theorisations are used which consider collective ideas, customs and behaviours which often stress equity or inclusion. Nuances are understood through cultural processes/elements such as space, time, identity, narrative, justice and power. This means that the strongest criteria to manifest are **Inclusion/personalisation and empowerment**, **Collaboration** and **Real-world connections**. This relates to an emphasis on attending to cultural elements such as race, gender, sexuality etc often through social justice lenses, from individuals' points of view but with a strong understanding of the human collaboration that supports and generates cultural phenomena. Situating these within STEAM activities that emphasise Real-world connections as part of attending to space, time, identity etc is almost fundamental to how the criteria manifest in these approaches. As with other approaches **Creativity** takes a supporting role, here conceptualised in terms of dialogue and collaboration, often with co-constructed and social-justice activist leanings. In background facilitation roles are **Thinking-making-doing** and **Disciplinary Inter-relationships**. These criteria are relevant but in a way which sees practical activities and disciplinary relations as supportive of cultural justice and equity rather than as the driving forces in this kind of STEAM activity. This all occurs through equitable practices grounded in a relational approach to the world.

This manifestation of the criteria through the Cultural and Equity approaches is brought to life in the example that follows:

Example 4: A Cross-curricular Digital Tear-off Calendar

*This example is drawn from the EU CREAM project (https://creamproject.eu/) and connects closely to theoretical lenses within the cultural and equity approaches such as culturally responsive and social justice pedagogies. The digital tear-off calendar was produced for interactive whiteboards as a daily set of resources that can be used as a 'culture snack': each calendar page shows philosophical questions, interactive games or creative activities where works of art are connected to other school subjects including STEM subjects. With the aim of engaging students in art around them, in their local context and beyond through and across the curriculum, it fosters an open school, connected approach. The examples offer opportunities to engage pupils in **dialogue** about diversity in culture and history. Cultural and Equity approaches foreground the criteria for STEAM practices of **inclusion and empowerment, collaboration** and **real-world connections**. For example, the* anatomic lesson *calendar page could trigger dialogue with pupils with respect to both the art work itself, anatomy in biology, historical questions of representation of women and the global majority* *with respect to medicine etc.*

Figure 17: Image used in the CREAM project materials: Der Anatomishce Les Van Dr Nicholaes Tulp. Rembrandt (1632)

5. Discussion and Conclusion

This deliverable sought to develop a comprehensive conceptual framework for STEAM, aiming to cover all its aspects and promised positive impacts in relation to the core foci of the Road-STEAMer project. We undertook a review of literature which draws upon theoretical or conceptual frameworks to explore and explain the impact of STEAM practice. Utilising systematic literature search protocols, we found relatively few examples of such theoretical frameworks in place, within the specific focus of our searches (as detailed above in the methodology section).

The theories or conceptual frameworks which were referenced in the literature were diverse in their nature, although they can all be considered to follow a ‘relational’ lens. We argued in this deliverable that this lens allows us to reflect how objects and people are related to one another, and why this is fundamental for STEAM education. This relational perspective is a foundational concept within this framework, suggesting that in STEAM practice we should consider how the different elements brought into relation in STEAM practices influence and are influenced by the others. These include the people, communities, disciplines and environments in which STEAM practices take place.

Our analysis led us to organise the theories into four approaches all of which can be understood as rooted in relationality in different ways: experiential real-world approaches; human psychological and cognitive approaches; social, spatial and material interconnectivity approaches; and cultural and equity approaches.

We then considered the relationship between these approaches and the criteria developed in the deliverable D4.1, to ensure consistency between these outputs and to acknowledge the importance of the D4.1 criteria for practitioners and policymakers for understanding and planning for effective STEAM practice. Each approach suggested a spotlighting or foregrounding of differing criteria, providing an effective mini roadmap of theories and constructs for practitioners to navigate, rooted in that fundamental relational conceptualisation of STEAM practice. Furthermore, deliverable D2.2 and deliverable D4.1 in combination are being turned into web resources for practitioners and policy briefings. Those created in the initial stages of this project should be seen as provocations for further refinement and exploration through the application of the ongoing co-creation methodology across the life of the Road-STEAMer project. It is important to emphasise again at this point that this framework is a state of the art, in Europe, at this point, within this particular project’s focus. Thus, the framework has space in it for further developments as conceptualisations grow across the life of the project.

The deliverable D2.2 conceptual framework brings a rigour of understanding to the 4.1 criteria – a linking of the relationship between the aims of STEAM practice and the effects under investigation, and a “coherent and holistic view of phenomenon” (Chijioke et al., 2021). It allows us to transfer good practice across different contexts and is essential to help us answer the questions we wish to explore of why STEAM can prove particularly useful in the analysed socioeconomic context in order to address the identified needs of deliverable D2.1. The results of deliverable D2.1 indicate that STEAM participation and achievements are still heavily impacted by a family's socio-economic condition as well as their educational and science capital. Intersectional aspects such as gender and 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.

To counteract some of the identified gaps in participation and attainment in STEM and to meet the identified needs such as a need for more inclusive pedagogy, the integration of the arts in STEM education is promising. Holistic STEAM education with emotional and appealing materials and approaches where 'art' is a way of enhancing self-confidence and facilitating the development of personal opinions and critical thinking may lead to more scientists in the long term, which resulted as another identified need. Many of the approaches in the conceptual frameworks described above as laying the ground for STEAM education are promising to cover these needs. For instance, experiential real-world interaction approaches cover several recommendations stemming from the work in task 2.1 (Focus on societal challenges and real problems to promote interest in science; Better connection between the needs of the labour market and lifelong learning).

The conceptual framework outlined here, consisting of a) an underpinning concept of STEAM as relational, b) a set of four thematic groups of theoretical approaches, which enable c) the spotlighting of key criteria for effective STEAM practice, will be an important foundation for the Road-map to be developed in Work Package 5 (Synthesis of the STEAM roadmap) - of this project. This conceptual framework will support the ongoing mapping and analysis of current STEAM practice as well as offering theoretically grounded guidance for the planning of new STEAM activities, enabling policymakers to consider the different elements needed for the design and development of coherent STEAM education to address the important issues identified in 2.1.

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7. Appendix

STEAM in European Union documentation

European Union (EU) literature does not provide one single definition of STEAM. A number of descriptions can be found in various documents, which generally include two aspects:

On the one hand, the "A" in STEAM is described as including a range of distinct elements such as "arts", "applied arts", "social sciences and the humanities", as well as "creative thinking", "real-world problem-solving" and "practical applications", and more generally an "interdisciplinary approach".

On the other hand, benefits of adopting a STEAM approach are identified mainly in the field of STEM education, including the promotion of "creativity", "innovation", "transversal competences", "soft skills", "communication", "critical thinking", "collaboration", as well as "increasing student engagement".

For example, in the Horizon Europe call topic under which Road-STEAMer is being funded, STEAM is defined as "the use of artistic approaches to STEM involving creative thinking and applied arts (the "A" in STEAM)" (Cordis, 2022).

In a recent initiative of the European Commission towards a "Manifesto for gender-inclusive STE(A)M education and careers" based on consultation with stakeholders, it is stated that "the STEAM approach to STEM refers to the inclusion of arts, social sciences and the humanities in STEM education or careers". It is also added that this approach "develops transversal competences, creativity and innovation that may make STEM studies and careers more attractive for women" (European Commission, 2022).

The European School Education Platform devotes an article to ideas and resources for educators to introduce STEAM in the classroom. In that article, it is defined that "STEAM (science, technology, engineering, arts, and mathematics) is an innovative approach to learning that promotes creativity and increases student engagement by integrating arts into scientific subjects". It is also mentioned that while science, technology, engineering, and mathematics are traditionally taught in an isolated way, “STEAM is an interdisciplinary approach to learning that seeks to modernise the way STEM subjects are taught”. In addition, it is argued that while STEM subjects are focused on enhancing students’ technical abilities, through STEAM students also develop soft skills important for the future of work, such as communication, critical thinking, collaboration, and problem-solving skills. Further, STEAM is promoted in the same article as a way to combine “theoretical knowledge with practical applications that encourage students to find solutions to real-world problems” (.

STEAM in OECD documentation

A clear, specific focus on STEAM is not as evident in education-related literature of the Organization for Economic Co-operation and Development (OECD) as it is in documentation from the European Union (EU). However, the work carried out by OECD in the fields of science education and arts education provides useful insights into how the relation between STEM and the “A” in STEAM might be envisioned in this context.

In 2013 OECD published a meta-analysis of the impact of arts education on non-arts skills (Winner, Goldstein and Vincent-Lancrin, 2013). “Arts education” in this report is understood to include arts classes in school (music, visual arts, theatre, dance classes), arts-integrated classes (where the arts are taught as a support for an academic subject), as well as arts study undertaken outside of school (e.g. private music lessons, out-of-school classes in theatre, visual arts, dance). The report analyses existing empirical knowledge about the positive effect that arts education can have on performance in non-arts academic subjects, including mathematics and science, in terms of developing critical and creative thinking and strengthening students’ academic motivation, self-confidence, and ability to communicate and co-operate effectively. Specifically, the report argues that arts education seems to have a positive impact on the three subsets of “skills for innovation”, namely subject-based technical skills, skills in thinking and creativity, and behavioural and social skills. Importantly, it is noted that “for all children, the arts allow a different way of understanding than the sciences. Because they are an arena without right and wrong answers, they free students to explore and experiment” (p. 19). In addition, it is stated that “artists, alongside scientists and entrepreneurs, are role models for innovation in our societies” (p.22).

Regarding STEM, the work of OECD on the Programme for International Student Assessment (PISA) provides evidence from a large number of countries across the world regarding secondary school students' science competences and the proportion of the students who perform at different levels of proficiency. The PISA assessment of science focuses on measuring students' ability to engage with science-related issues and with the ideas of science, as reflective citizens. Concepts predominantly associated with the "A" in STEAM are not strongly represented in the assessment and the notion of creativity, where it appears, is directly linked to scientific knowledge and skills. Thus, at proficiency Level 5 on the science scale, students are considered "top performers in science" in that "they are sufficiently skilled in and knowledgeable about science to be able to creatively and autonomously apply their knowledge and skills to a wide variety of situations, including unfamiliar ones" (OECD, 2018).

OECD has also published a few reports focused on how different pedagogical approaches can help innovate education, including in STEM. An example from the field of mathematics is a report on how mathematics education can foster the skills that are appropriate for innovative societies (Mevarech and Kramarski, 2014). The report puts emphasis on the key role of metacognitive pedagogies in this, which "can be used to improve not just academic achievement (content knowledge and understanding, the ability to handle unfamiliar problems etc.) but also affective outcomes such as reduced anxiety or improved motivation" (Mevarech & Kramarski, 2014).

Another recent and ongoing piece of work by OECD showcases how embedding innovation skills such as creativity or critical thinking in the curriculum can lead to deeper and more engaged learning (Vincent-Lancrin et al., 2019). The report is accompanied by corresponding rubrics and lesson plans for different subject areas, including science and arts.

Conceptual rubrics are designed to clarify "what counts" or "what sub-skills should be developed" in relation to creativity and critical thinking and to guide the design of lesson plans and support discussions about those skills in the classroom. Domain-general versions are applicable across subjects, and domain-specific derivatives use the language of taught subjects. Assessment rubrics articulate levels of progression or proficiency in the acquisition of creativity and critical thinking skills and can be used for formative or summative assessment by teachers, or by students to self-assess their own progress.

On the other hand, the lesson plans are examples in different subject areas aiming to inspire teachers by making visible the kind of approaches and tasks that allow students to develop their creativity and critical thinking while acquiring the content and procedural knowledge across different domains of the curriculum.

In this context, Vincent-Lancrin (2022) focuses specifically on redesigning teaching and learning within existing science curricula so that students have more space and appropriate tasks to develop their creative and critical thinking skills. The development of conceptual rubric on science is described, and examples of science lesson plans and pedagogies are given, and some key challenges for teachers and learners are reflected on.

Interestingly, in defining the link between science and creativity and critical thinking, Vincent-Lancrin (2022) focuses specifically on the fact that critical thinking and creativity are at the core of scientific practice. Therefore, he argues, “teaching and learning creativity and critical thinking in science education in schools is thus one way to “think like a scientist” and understand the values of science, even if, like for the technical skills in science, that is, the mastery of content and procedural knowledge, students are not necessarily expected to be as proficient as expert scientists – not to mention the most celebrated ones” (p.36).

Regarding creativity in particular, Vincent-Lancrin (2022) notes:
“Scientists usually need to have creative or original ideas to receive grants and get published in scientific journals. Scientific awards (such as the Nobel Prizes) typically celebrate advances that bring some ideas or techniques that are “new to the world” (and in this sense, creative in the full meaning of the word). One aspect of scientific practice that is usually somewhat downplayed is “imagination” (p.35).

It is nevertheless a key aspect of science as Nobel Prize winner and famous physicist Feynman (1963) noted:

Experiment is the sole judge of scientific "truth." But what is the source of knowledge? Where do the laws that are to be tested come from? Experiment, itself, helps to produce these laws, in the sense that it gives us hints. But also needed is imagination to create from these hints the great generalizations — to guess at the wonderful, simple, but very strange patterns beneath them all, and then to experiment to check again whether we have made the right guess. This imagining process is so difficult that there is a division of labor in physics: there are theoretical physicists who imagine, deduce, and guess at new laws, but do not experiment; and then there are experimental physicists who experiment, imagine, deduce, and guess. (p. 1 - 1)" (p. 35-36).

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