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Practice or Praxis? A Theoretical Classification System for STEAM Education

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Abstract: Research in STEAM education continues to develop, and yet the literature in this area is often theoretically 'light'. Given the importance of theory to provide explanatory power, the aim of this paper is to offer a theoretical classification system to be used as a tool for researchers and practitioners in this area. Derived from literature searches on STEAM education within open science/schooling, secondary/tertiary education intersection and global challenges, 26 frameworks were identified from 26 academic sources and refined based on their coherence and strong theoretical heritage. A relational ontology was proposed as a recurring theme and is a foundational aspect of the final classification system, signifying a shift from traditional models of STEAM that trivialise the 'arts' as utility disciplines. The 26 individual frameworks are organised into four approaches: 'experiential real-world interactions', 'human psychological and cognitive', 'social, spatial, and material interconnectivity', and 'cultural and equity'. The overall classification system provides a starting point for researchers and educators navigating theoretically driven yet diverse STEAM implementation and understanding its impact depending on, and in response to, their preferred methodology. This system is novel in its treatment of theoretical perspectives, and its dynamic nature allows for the inclusion of further frameworks in the future.

Keywords: STEAM education; classification system; praxis; conceptual framework; theoretical framework; relational ontology; transdisciplinary

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1. Introduction

STEAM (science, technology, engineering, arts, and maths) approaches to education are growing increasingly popular in the bid to diversify participation in technical career pathways (Kijima et al., 2021); encourage interdisciplinary and transdisciplinary working (Hughes et al., 2022); and tackle 'wicked' problems such as the climate crisis and poverty (Marmon, 2019). STEAM is a relatively new interdisciplinary/transdisciplinary methodology, with the academic literature only emerging in the last decade (Aguilera & Ortiz-Revilla, 2021). However, as Colucci-Gray et al. (2017) note in their BERA-commissioned report on STEAM education, much of the extant STEAM literature suffers from a lack of conceptual clarity as to what STEAM is. This may be partially attributed to the lack of

consensus as to how STEAM is defined and what the purpose is of the 'A', or 'the arts', within the STEAM framework. According to Perignat and Katz-Buonincontro (2019), there is a tendency for researchers and practitioners to begin with the relationship between the disciplinary components of STEAM, i.e., the sciences, technology, engineering, arts, and maths, followed by the classification of STEAM as interdisciplinary, transdisciplinary, multi-disciplinary, or cross-disciplinary. The incongruity then lies in how these varying definitions are used to identify a practice as 'STEAM' (Chappell & Hetherington, 2023; Chappell et al., in review).

We contend that a further challenge to effective STEAM education is the inconsistent use of theory in its practice—something that we have previously observed and is substantiated in the study reported here. Practice without theory is arguably incongruent with the transformative nature of STEAM. How can one capture if and what transformation has taken place without the use of theory? As Patti Lather observed, in her seminal article *Research as Praxis*, praxis—'the dialectical tension, the interactive, reciprocal shaping of theory and practice'—is at the centre of emancipatory social science (Lather, 1986, p. 258). Thus, if we want to understand the impact of STEAM practice, we must turn to STEAM praxis. There is, however, a dearth of conceptual frameworks—networks of interrelated concepts that, combined, provide 'a comprehensive understanding of a phenomenon or phenomena' (Jabareen, 2009, p. 51)—or theoretical frameworks—where theory is applied to understand phenomena (Anfara & Mertz, 2015)—developed specifically to capture the impact in this field. The few frameworks that do exist tend to focus on specific aspects of STEAM—for example, the integration of STEAM into formal educational settings, e.g., Ng et al. (2022), or an evaluation of STEAM activities based on specific competencies, e.g., Ussher et al. (2023). Indeed, it is arguable that a single conceptual framework for STEAM practice is inappropriate and theoretically reductive. A responsive theoretical classification system that groups relevant theories and concepts, however, would be an invaluable resource for practitioners seeking to achieve emancipatory aims but struggling to navigate the diverse range of theories and frameworks across the social sciences.

This paper reports on such a theoretical classification system for a specific area of STEAM practice, developed as part of the EU Road-STEAMer project (https://www.road-steamer.eu, accessed on 23 January 2025). The aim of this project is to develop a STEAM roadmap for Science Education in Horizon Europe and in educational policy across the European continent. This focuses on practice that bridges open science (i.e., making science accessible to laypeople and professionals alike (Vicente-Saez & Martinez-Fuentes, 2018)) and open schooling (e.g., field visits, remote learning, and collaborative projects focused on real-life challenges and innovations (Okada & Gray, 2023; Okada & Sherborne, 2018)). As noted, the definitions of STEAM vary; the Road-STEAMer project began by broadly defining STEAM as the incorporation of the arts to increase the impact and enjoyment of the teaching of science, technology, engineering, and mathematics (Cruz et al., 2021; Marín-Marín et al., 2021; Wu et al., 2022). But it has since developed a more nuanced understanding of the benefits of the more equal positioning of the arts combined with STEM within education to support citizenship for all genders (Hirshfield & Koretsky, 2018; Sultan et al., 2024) alongside more transdisciplinary practice (Quigley et al., 2019). Research within the project has also expanded the understanding of STEAM to incorporate its role in social cohesion (Unterfrauner et al., 2024), as well as foregrounding the use of problem-solving, inquiry-based, and project-based learning (Blumenfeld et al., 1991; Chistyakov et al., 2023) as a key characteristic of STEAM educational practice.

The study reported in this paper aimed to answer the following question: How can existing conceptual and theoretical frameworks for STEAM education, incorporating the arts and creativity, be mapped within the context of open schooling at the secondary–tertiary intersection? It achieved this by reviewing the existing literature that had applied

an established theoretical or conceptual framework to STEAM in these areas and then undertaking thematic analysis on the resulting papers. The result is a novel classification system, rooted in a relational ontological understanding of STEAM that reflects its dynamic, fluid, and (inter-/intra-)connected nature, which offers a tool to support those engaged in STEAM practice to identify relevant theories and concepts that may be applied to their work. There was also a project aim to theoretically inform the development of the policy roadmap. This paper complements Chappell et al. (in review) and Chappell and Hetherington (2023), which analyse existing practices and resources to articulate and understand the criteria that might be used to search out and collate strong STEAM practice and synthesise this into viable practice and policy recommendations.

2. What Do We Mean by 'Theoretical Classification Systems'?

This paper outlines a 'classification system' that identifies and describes objects, grouping them based on similarities (Lokker et al., 2015; Stavri & Michie, 2012). In doing so, a classification system, or scheme, can describe large sets of data or objects, thereby reducing the complexity, and support the study of relationships between them (Bailey, 1994). Thus, a classification system can support STEAM practitioners and researchers to engage with the huge range of theoretical and conceptual frameworks encompassed within the social sciences. Furthermore, the system serves to highlight the importance of using theory to understand the impact of STEAM educational practice, or, more specifically, the 'why' of the impact (Sutton & Staw, 1995), rather than relying on superficial measures or simply assuming that 'STEAM practice is good practice'.

Stavri and Michie (2012) identify six different types of classification systems within the natural, medical, and social sciences: nomenclature, ordered sets, hierarchical, matrices, faceted, and social categorisations. These classification systems are distinguished by, amongst other aspects, their purpose, structure, method of development, and ability to accommodate new discoveries. The classification system offered here can be argued to be a 'faceted' classification system, in that it provides an overall, hierarchical structure for the range of conceptual and theoretical frameworks currently in use to explore STEAM practice. As described below, the system was developed by consensus, and it is flexible to accommodate new discoveries or new uses of frameworks in the future.

We argue that this system will allow us to better understand what STEAM is in particular areas of study, how it should work, and the impact that it has made. As will be described in this paper, we propose that the frameworks used for STEAM within the academic literature in this area can all be connected through one ontological position: relationality. Furthermore, our analysis suggests that they can be organised into four approaches, each of which prioritises different epistemological and axiological positions: experiential real-world interactions; human psychological and cognitive; social, spatial, and material interconnectivity; and cultural and equity. Such a classification system offers a novel contribution to the field of STEAM education research and practice and, we argue, exemplifies a useful heuristic for the navigation of complex and under-theorised interdisciplinary fields of study. The remainder of this paper explains the process by which this system and the embedded concept of relationality were produced and offers a new definition of STEAM that positions it in a flexible and responsive way.

3. Relational Ontology

At the heart of the Road-STEAMer classification system is our argument that relationality is a foundational concept in how we view and understand STEAM practice. Stemming from an ontological position that foregrounds the mutual relations between 'things' (objects or subjects) as fundamental to their existence, this way of viewing the

nature of reality asserts that 'entities are what they are because of their relationships with other entities' (Spyrou, 2022). In other words, relations are understood as fundamental to the existence of the entities, objects, or disciplines that are in relation. Relations between relata are part of their existence: the relata, whether they be entities, objects, human beings, or disciplines, do not exist independently of the relationships they have with other relata. Relations of multiple kinds are found in STEAM practices (as is reported in this study), including relations between disciplines; between collaborating learners; and between learners and the context and materials through which they learn. A relational ontology places these different STEAM relations themselves (rather than the relata) at the heart of the theorisation of STEAM education.

This relational ontology can be linked to dialogic theory, in which the emergence of new thinking and understanding arises as a result of the relations between entities participating in the dialogue, which are themselves changed through this participation (Hetherington, 2024; Wegerif, 2011). This relational stance, drawing on Bakhtin, suggests that the 'voices' in the dialogue may be human or other-than-human and may include the 'voices' of texts, artefacts, art works, apparatus, and so on. Taking this relational ontological position into the field of education, and drawing on the literature at hand, our classification system is therefore rooted in the principle that there can be 'no [STEAM] education without relation' (Bingham & Sidorkin, 2004). This extends the arguments in Bingham and Sidorkin's edited volume focused on human relations to a broader understanding of relationality and its role in education.

In the analytical process described below, we noted that, in the STEAM literature analysed, relationality was key to the framing of STEAM across a range of different theoretical and conceptual positionings of STEAM, whether this relationality be between disciplines, human collaborators, or cultures or between humans and 'real-world' contexts. For example, Guyotte (2020) places relationality as one of three key strands in their conceptual framework for STEAM in the Anthropocene, alongside transdisciplinarity and responsibility. Noting this, we argue for a relational *ontological* stance, linked to a broad understanding of the relational dialogue between a range of relata (e.g., teacher–student in education), but also the importance of relations between disciplines, between settings, and between humans and the 'real world' with which they interact. Positioning relationality as an ontology, i.e., the nature of reality, underpins our means of understanding and viewing STEAM through the relations themselves, highlighting within our classification system the different ways in which relations are fundamental to STEAM. As a result, a relational ontology became the foundational concept for the proposed classification system, with the different approaches characterised and therefore grouped by relations of a different type.

4. Materials and Methods

The study reported in this paper had two significant components: a scoping review (Arksey & O'Malley, 2005; Mays et al., 2001) of STEAM research and a co-creation workshop to complement and validate the findings of the literature searches with the research through a co-design methodology (Busciantella-Ricci & Scataglini, 2024). The following section will outline these processes in further detail.

4.1. Search Strategy

This study was conducted as part of the EU Road-STEAMer project, with the intention of mapping existing theoretical and conceptual STEAM frameworks that bridge open science and open schooling within the gap between secondary and tertiary education. These parameters delineated our search, and the resulting classification system is

representative of this. Thus, we included the concepts of STEAM, open schooling, open science, secondary education, tertiary education, and appropriate synonyms in our search terms.

4.2. Search Terms

We searched for the following terms within journal titles, abstracts, and keywords: (steam OR "Science, Technology, Engineering, Arts, and Mathematics" OR stem AND art OR creativ*) AND (real-world OR everyday OR real AND life OR "open schooling" OR "open science" OR community) AND (secondary OR tertiary OR higher OR school OR college OR university OR undergraduate OR outreach AND educat*).

4.3. Database Searching

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

4.4. Inclusion Criteria

To be included, the articles were to required to

a. Be on the topic of the paper on STEAM in an educational setting (formal, informal, or nonformal);
b. Make reference to a theoretical or conceptual framework or include a 'theory' or 'construct' or 'concept' that may be used to look at STEAM practice;
c. Be published in a peer-reviewed source OR considered 'grey literature';
d. Be in the English language, with an option to include Road-STEAMer consortium members' home language publications with translated abstracts.

Given the relatively small number of articles generated, the concepts of the education phase (i.e., secondary–tertiary transitions) and 'open science' were not used as strict inclusion or exclusion criteria, to allow for the inclusion of theories or concepts that could be generically useful across education phases for STEAM work. The inclusion of grey literature, such as conference proceedings, is considered important in a scoping review to map the full extent and nature of the research activity in a topic area and to support the development of the field (Paez, 2017; Pham et al., 2014).

4.5. Additional Search Strategies

All Road-STEAMer consortium partners were asked to nominate articles that met the project focus on STEAM at the intersection of secondary/tertiary education, which involved arts methodologies and/or open science and open schooling, and, crucially, which included a theoretical or conceptual framework.

4.6. Selection Process

After the initial database searches, the results were exported to Endnote (v.20). Duplicates were then deleted and the remaining references exported to an Excel spreadsheet. While 'English language' was an inclusion criterion, we did invite project partners to propose suitable papers within their home languages; however, none were forthcoming. Nominated English-language articles from consortium partners were also added to this spreadsheet and duplicates removed. This process generated 139 articles. The authors of this paper, along with consortium partners from the Road-STEAMer consortium project, then screened the titles and abstracts of each reference. From the identified papers that fit the inclusion criteria (N = 87), 49 (56%) included reference to a theory, construct, or concept (N = 43).

4.7. Analysis

The authors of this paper undertook an analysis of the 43 frameworks identified in the literature searches. The first step was a further screening stage, whereby concepts that were poorly defined or did not have a strong theoretical 'heritage', i.e., had not been sufficiently explained, justified, and applied in the paper or in the previous academic literature, were removed. Similarly, papers without a coherent and identifiable framework of some kind were removed. For example, several papers took a design-thinking approach to STEAM, yet they focussed on the process aspect of design thinking, rather than drawing on design theory (Buchanan, 1992) or other frameworks associated with design thinking, such as Dewey's work on aesthetics (Kimbell, 2011), to explore any impact that their approach may take.

This process led to the identification of 26 frameworks derived from 26 journal papers, books, and conference proceedings, with some sources mentioning several theories, while some theories appeared in more than one source. A list of the sources and associated frameworks is included in the appendices for this paper (Appendix A).

The 26 frameworks were then summarised in the digital collaborative visualisation tool Mural (www.mural.co, accessed on 23 January 2025). The authors used the mural to undertake a thematic analysis through a dialogic process. The analysts used the principle of constant comparative analysis (Fram, 2013) to familiarise themselves with the data (in this case, papers) and, driven by their aims, generate lower-level codes (in this case, the theories and concepts), which were then constantly compared to develop categories for thematisation. Initial discussions pointed to the recurrence of the concept of 'relationality' (see above); thus, particular attention was paid to the nature of the relations within each framework shortlisted.

4.8. Additional Data Collection

A key feature of the Road-STEAMer project's methodology is the use of co-creation workshops with STEAM stakeholder communities. The intention of this methodology is to develop outputs generated through dialogue and mutual learning, in line with the project's participatory methodology principles. A co-creation workshop was held after the initial analysis phase, with participants (N = 30) who could engage in a high-level discussion regarding the use of theoretical frameworks, including academics and professionals engaged in STEAM practice.

During the workshop, the authors used the online digital collaboration tool Mural, to facilitate a discussion around the classification system produced in the initial stage of analysis. The participants were also introduced to a visualisation of the classification system. Feedback from this workshop was used to refine the system and, particularly, the visualisation, leading to their final form as detailed below.

5. Results

In this section, we outline examples of some of the theories, concepts, and frameworks identified in the literature searches, and the proposed four approaches that comprise the classification system offered here.

Having a relational ontology underpinning our conceptualisation of STEAM suggested that the theoretical classification system developed to guide our study of STEAM practices and policy needed to focus on how relations between different elements of STEAM practice create and impact the practices themselves. However, despite noting the importance of relationality in our analysis of the STEAM literature described above, it is important to be clear that the original sources found in the literature largely did not use the same relational ontology as a conceptual grounding for their work. The relational

stance identified through and used in our analytical process foregrounds relationality in a way that may not have been the case in the original research. So, for example, the original research reviewed may have focused on STEAM learning through real-world contexts (e.g., Stroud & Baines, 2019). Through our classification system, we identified the relation between the learners and the real-world context as a key element in this STEAM practice, but the original research did not explicitly identify a relational ontology as part of this practice. This means that, as the theoretical and conceptual frameworks described below in the proposed Road-STEAMer classification system are used in the interrogation or development of policy and practice, it is important to consider how this framework sits within a relational ontological stance. To support this stance and the way in which relationality is a foundational concept within the Road-STEAMer classification system articulated in this paper, we have developed a visual, which is provided in the section below, to highlight the network of relations between different actors within STEAM policy and practice.

5.1. The Theoretical Classification System

Keeping in mind the key concept of 'relationality' as our ontological perspective, the 26 conceptual and theoretical frameworks identified in the sorting process were organised into four approaches, each sharing a common relational nature (as described above in 'Analysis'). These approaches were 'experiential real-world interactions', 'human psychological and cognitive', 'social, spatial, and material interconnectivity', and 'cultural and equity'. Table 1 shows the approaches in more detail, including the five to nine frameworks used within STEAM activity, which were identified in the initial literature searches. Further explanation of each of the approaches can be found below.

Table 1. The four approaches and their frameworks.

Experiential Real-World Interaction Approaches	Human Psychological and Cognitive Approaches	Social, Spatial, and Material Interconnectivity Approaches	Cultural and Equity Approaches
Active Learning		Affirmative Ethics	Critical Pedagogy
Aesthetics	Bloom's Learning Taxonomy	Connected Learning	Culturally Responsive Pedagogy
Constructivism	Creative Thinking	Nexus Theory	Narratives
Creative Inquiry for Transdisciplinarity	Five Creative Dispositions Model	Slowing	Identity Theory
Dewey/Learning Through Experience	Flow State		Social Justice Pedagogy
	Resilience	Space–time and culture	
	Resourcefulness	Social Network Theory	
	Self-efficacy	Social Practice Theory	
	Torrance Test of Creativity	Transdisciplinary/creativity through spatiality/materiality beyond the human	

Figures 1 and 2 (below) provide a visualisation of the classification system. Figure 1 shows a single pyramid with four coloured faces (chosen for visual interest, rather than for symbolic meaning) to represent the four approaches identified. The pyramid metaphor was chosen to represent the distinct but connected characteristics of each approach, staying true to the relational ontology of the system.

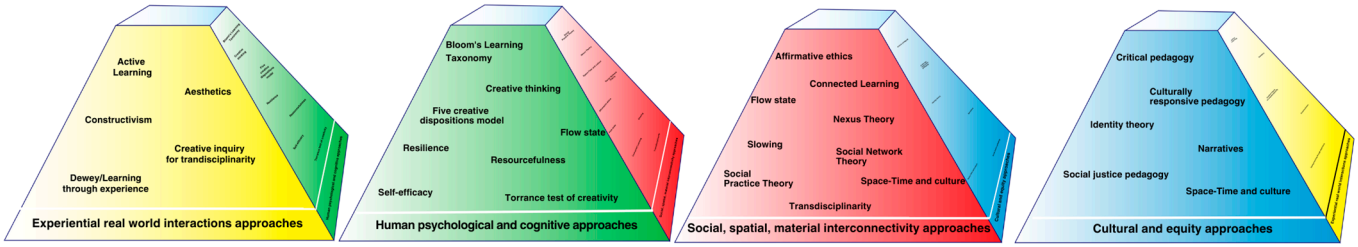

Figure 1. Side visualisation, with rotations, of the meta-framework.

Figure 2 shows the same pyramid from an aerial perspective to demonstrate the relational ontology as the relations between the four approaches—situating the approaches themselves as relata. This visualisation also shows how some of the frameworks are situated in more than one approach. Indeed, we would argue that there is more fluidity in the relations between the four approaches than is perhaps possible to demonstrate in any visualisation.

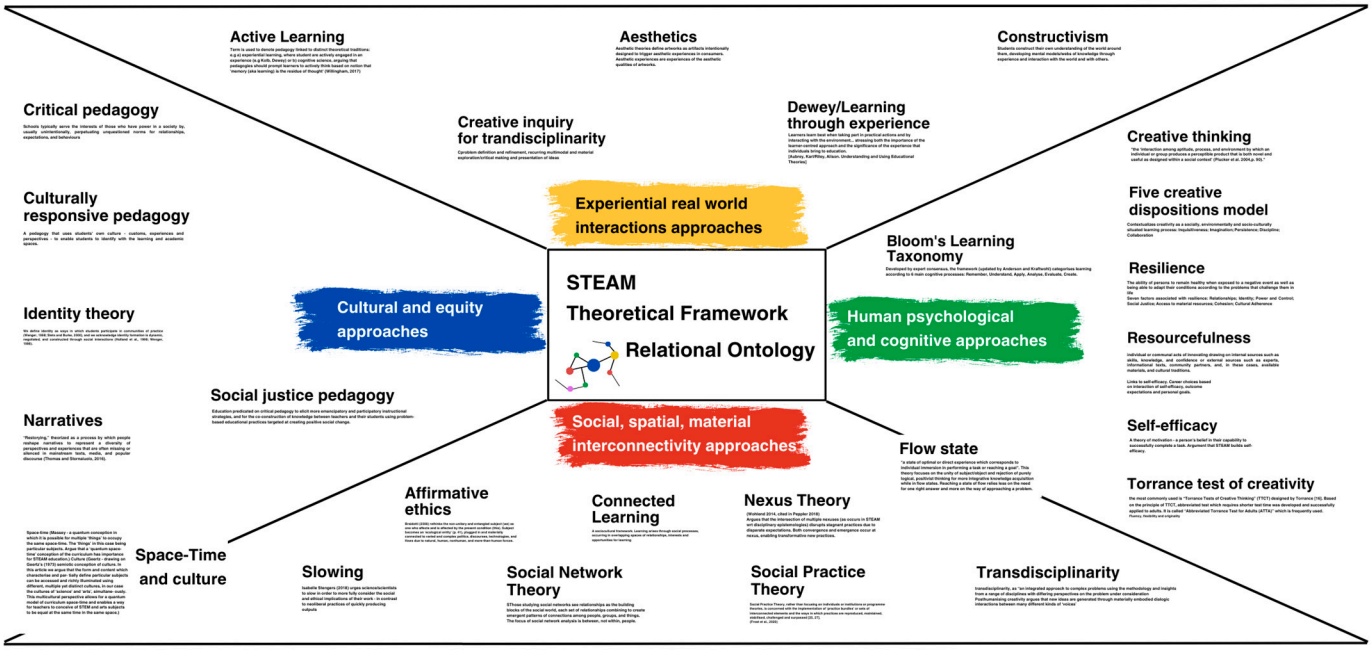

Figure 2. Aerial visualisation of meta-framework.

While it may be easy to interpret the pyramid as separating elements from one another, it is important to understand that our model considers these as part of a whole picture of the different ways in which people have approached STEAM practices—all of which we see as relational.

Next, each of the four approaches is defined and explained in relational terms. Two examples of theoretical or conceptual frameworks for each of the approaches are also detailed in the sub-sections below, chosen to include theories that are associated with both STEM (science, technology, engineering and maths) and arts pedagogies. The theories are defined and discussed within the context of the papers from which they were derived. Further analysis is then provided of the connections between the theory, relationality, and STEAM.

5.2. Experiential Real-World Interaction Approaches

These frameworks all place a 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. STEAM praxis that we identified as theorising STEAM activity through real-world contexts, and experiential interactions with those contexts and material environments, were often linked to the notion of inquiry and the importance of active investigation and the exploration of the world, often rooted in the work of Kolb (2015) and Dewey (1963). The idea that students create their own understanding of the world around them through this interaction is also a common feature of this set of frameworks, rooted in constructivist theory, which is highly influential in science education (Sjøberg, 2007) and is extended in some of these papers to STEAM. Within these experiential frameworks, the idea of a relational interaction with the real world is fundamental: learners need to connect, observe, experiment, problematise, and create within the context of the real world and using materials and physical engagement with the real world. These kinds of relations and interactions with the real-world context are nuanced through the different framings used, but, at heart, these frameworks foreground the idea that STEAM learning occurs within a relation between the learner and the real world.

The papers in this approach focussed on STEAM framed via active learning (Caratozzolo et al., 2021); aesthetics (Mehta et al., 2019); constructivism (Domenici, 2022); creative inquiry for transdisciplinarity (Costantino, 2017); and Dewey/learning through experience (Stroud & Baines, 2019). Two examples of theories or concepts organised in this group are as follows.

5.2.1. Dewey/Learning Through Experience (Referenced in 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 that 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 a reflective note-making method as learners undertake an inquiry, adding an additional dimension to their interactive relationship with the real-world topic of their inquiry. They use this framing to show how the arts can be drawn into an experiential inquiry process for STEAM learning, fostering a relation between disciplines through iterative relational, experiential interactions with the topic of inquiry through different disciplines.

5.2.2. Creative Inquiry for Transdisciplinarity (Referenced in Costantino, 2017)

This framework is articulated by Costantino (2017), who sees creative inquiry as an iterative process, focused on problem definition and refinement, recurring multimodal and material exploration/critical making, and the 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. Citing Dewey (1934), they argue that signature pedagogies in art and design with respect to critical making and object-based learning are key to creative inquiry, which is presented as a model for transdisciplinary curriculum and pedagogy, including STEAM (Costantino, 2017). These frameworks demonstrate clear similarities with inquiry-based science education with respect to the fundamental role of real-world experiential interaction, albeit with a different focus for the relation with the real-world and drawing on different disciplinary knowledge in supporting this relational learning. However, connecting art and design-based creative inquiry as a model of real-world interactions with that in scientific inquiry, engineering design, and so on offers a model for STEAM learning in which

the disciplinary relationship is fostered through creative inquiry-based interaction and relationality with the real world.

5.3. Human Psychological and Cognitive

These sets of frameworks labelled as 'human psychological and cognitive' are grounded in the psychological tradition and demonstrate cognitive theorisations (focussed 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. Many of these frameworks are focused on creativity as the connection across STEAM disciplines, taking a human psychological or cognitive stance to understand creativity. Whilst this set of frameworks is the least clearly connected to the overarching relational ontology that we have identified as key to conceptualising STEAM, since they tend to focus on what is going on in the mind, the way that they are drawn upon in the literature connects human cognition in STEAM activities and learning through STEAM in ways that we see as relational. For example, they explore a cognitive understanding of creativity as the vehicle to relate STEAM disciplines—in other words, creative thinking as the means by which the relation between STEAM disciplines occurs. The way in which thinking occurs via a real-world stimulus, which in a STEAM context may occur through multiple disciplinary methodologies, particularly with respect to creativity (e.g., Harris & de Bruin, 2017), can be viewed as essentially a relation via creative thinking between disciplines, the real-world context, and STEAM. Similarly, the examination of creative thinking in groups (see, e.g., creative thinking, Chen & Lo, 2019) is intrinsically focused on the relational through the group thinking process.

The papers in this approach focused on STEAM framed via Bloom's learning taxonomy (Del Valle-Morales et al., 2020); creative thinking (Chen & Lo, 2019); creative dispositions (Harris & de Bruin, 2017); flow states (Dredd et al., 2021); resilience (Del Valle-Morales et al., 2020); resourcefulness (Avendano-Uribe et al., 2022); self-efficacy (Boice et al., 2021; Full et al., 2021); and Torrance tests of creativity (Chang et al., 2019). Two examples of theories or concepts organised in this group are as follows.

5.3.1. Self-Efficacy (Referenced in 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).

Self-efficacy is a popular construct to understand engagement/disengagement and persistence in STEM. Recent work has also applied this to STEAM, offering self-efficacy theory as a means of understanding the impact of STEAM on learners. Relationality in this respect is focused on the way in which the individual's sense of self-efficacy is influenced by the STEAM context and their wider environment, including their previous levels of success with respect to STEAM disciplines individually or STEAM methodologies in prior learning. Self-efficacy has been drawn upon to understand STEAM practices—for example, by 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. Whilst self-efficacy is focused on the individual's perception of themselves, a relational ontology pushes us to focus not simply on the individual, but on their relationships with the wider STEAM context, activity, and practices with which they are engaged.

5.3.2. Creativity Frameworks (Referenced in Chang et al., 2019; Harris & de Bruin, 2017)

'Torrance tests of creative thinking' (Chang et al., 2019; Torrance, 1966) and the five creative dispositions model (Harris & de Bruin, 2017) offer two frameworks for creativity that appeared in our searches. 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 that Torrance developed measure four components: fluency, flexibility, originality, and elaboration. Chang et al. (2019) used these tests to measure the influence of the interactive art of visual music on the creativity of science and engineering students, although it is noted that the STEAM focus of the paper is on the potential future uses, rather than how it was used in the study itself.

The five creative dispositions model (Harris & de Bruin, 2017) contextualises creativity as 'a socially, environmentally and socio-culturally situated learning process' (p. 158) and identifies individual dispositions of inquisitiveness, imagination, persistence, discipline, and collaboration. Harris and de Bruin (2017) used this theoretical model to investigate creativity across disciplines in an international study. In both of these frameworks, used in a STEAM context, the focus is on creativity as both a method of STEAM and an outcome of STEAM. With respect to relationality, although not made explicit in the literature that we drew upon in our analysis, our analysis identified creativity in these frameworks as a human way of thinking that can either (a) be developed in STEAM practices through the relation between disciplines or (b) be the means by which the disciplines interact in STEAM practices. Guilford's (1950, 1967) work on divergent thinking, considered to be a fundamental aspect of creativity, proposes that new solutions are developed by new ways of thinking, often stemming from new and unexpected combinations of thoughts—highlighting the dynamic nature of relational thinking within creativity.

It should be noted that other theoretical perspectives on creativity with STEAM are less focused on human cognition and creative thinking and are broader ways of exploring creativity—including with respect to STEAM practices—through, for example, embodied dialogue (Chappell et al., 2019) and posthumanising creativity (Chappell, 2022), which have strong relational elements. However, in our classification system, these facets of theorising creativity in transdisciplinary or STEAM settings were categorised within 'social, spatial, and material interconnectivity'.

5.4. Social, Spatial, and Material Interconnectivity

These frameworks theorise STEAM through an emphasis on interconnectivity, considering human beings in relation to many kinds of others, including material elements, space, time, and affect, often grounded in socio-materially conceived ideas, drawing on the likes of Barad (2003) and Stengers (2018). Relationality between humans and other-than-humans, with an accompanying focus on de-centring humans to allow for qualitatively different relationships, characterises STEAM education work within this approach. The nuances of interconnection are considered through connection-making, nexuses, networks, and processes such as slowing and flow.

The papers under this approach focused on STEAM framed via affirmative ethics (Guyotte, 2020); connected learning (Bass et al., 2016); flow states (Dredd et al., 2021); nexus theory (Peppler & Wohlwend, 2018); slowing (Guyotte, 2020); social network theory (Boice et al., 2021); social practice theory (Quigley et al., 2019); space–time and culture (Davies & Trowsdale, 2021); and transdisciplinarity and creativity through spatiality and materiality (Chappell et al., 2023). Two examples of theories or concepts organised in this group are as follows.

5.4.1. Affirmative Ethics (Referenced in Guyotte, 2020)

Affirmative ethics, as advocated by Braidotti (2006), takes a relational perspective in which the subject (we) is entangled in a social and material present: an 'ecological entity' that is materially connected to humans and other-than-humans 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. Guyotte argues for this as a philosophical mechanism, fostering spaces for transdisciplinary conversations in order to respond to critical Anthropocentric issues. They actively see relationality as conjoined with responsibility and ethics to question how STEAM can be done differently. They argue against STEAM for a productive STEM workforce and see a relational STEAM methodology as more likely to be able to work *with* the complexities of the Anthropocene.

5.4.2. Flow State (Referenced in Dredd et al., 2021)

Csikszentmihalyi (1990) developed the concept of 'flow', whereby a 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, alongside positive psychology (Seligman, 2002), is derived from the concept of pure experience from Zen philosophy (Szymańska, 2002). Relationality can be seen in the way in which this theory focuses on the unity of subject/object and the 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 means of tackling a problem.

Dredd et al. (2021) use the flow state to compare how STEAM students and electrical engineering students experience their coursework, demonstrating flow as a productive way to understand the importance of enjoyment and personal interest within coursework in both disciplines and also showing flow as possible in both, with implications for the design of STEAM experiences. Relationality as understood via a Zen-connected subject–object can be seen as a further thread of STEAM relational conceptualisation within this paper and the wider classification system.

5.5. Cultural and Equity

These theoretical frameworks are situated in cultural perspectives, which include customs, material practices, traditions, and collective ideas, and often foreground equity and inclusion. A relational ontology speaks to a cultural and equity approach because it challenges the notion that, at the fundamental level of existence, the world is essentially passive and lacking in agency—instead proposing that social actors have access to reality through participation and engagement with it (Stetsenko, 2008). In foregrounding 'active connectivity', relational ontology acknowledges the dynamic and interrelated nature of cultural practices, aligns neatly with the group activism often required to achieve equity, and celebrates the collective differences that define inclusion.

The papers under this approach focused on STEAM via critical pedagogy (Chung & Li, 2021; Fletcher & Hernandez-Gantes, 2021; Kiyani et al., 2020); culturally responsive pedagogy (DeVito et al., 2020; Kant et al., 2018; Rao et al., 2021); narratives (Avendano-Uribe et al., 2022); identity theory (Avendano-Uribe et al., 2022; Claville et al., 2019; Full et al., 2021); social justice pedagogy (Fletcher & Hernandez-Gantes, 2021); and space–time and culture (Davies & Trowsdale, 2021). Two examples of theories or concepts organised in the cultural and equity group are as follows.

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

Critical pedagogy, initially developed by Paulo Freire, sees education as a pathway to social justice and democracy through critical consciousness and empowerment, where learners 'develop the knowledge and skills they need to undo oppressive structures and achieve liberation' (Saunders & Wong, 2020, p. 76). Margonis (1999) argues that Freire's ontological position was relational in nature, because, in his thinking, the student and teacher are social entities who are co-constructed due to their relationship with one another within their educational setting, and they are part of a larger whole. In moving beyond the individualism inherent in teacher-led or student-centred pedagogies, critical pedagogy prioritises dialogical relationships as the foundation for praxis.

We found several studies that explored STEAM practice as a form of critical pedagogy, including Chung and Li (2021); Fletcher and Hernandez-Gantes (2021); and Kiyani et al. (2020). In these papers, STEAM was argued as a method to awaken students' 'critical consciousness', especially regarding concerns that are specific to their communities. Kiyani et al. (2020) propose that STEAM practices can give students an opportunity to develop their creativity and innovation skills while addressing issues that are contextually authentic and culturally responsive, more so than STEM practices alone. By identifying problems that are responsive to students' needs, reflecting the rich, multifaceted nature of their lives outside of the classroom, STEAM practices that take a critical pedagogy methodology can strengthen the relational links between school and community. The student as a social entity more authentically represents this individual in all contexts.

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

Identity theories have been used in several disciplines to explore the impact of social interactions on the 'self'—specifically how the 'social nature of the self (is) constituted by society' (Hogg et al., 1995, p. 255). Relations are a central tenet of identity theories: relations between individuals, groups, communities, and 'things' or resources (Stets & Burke, 2000). Identity formation is argued to be a dynamic process; therefore, incorporating relationality into our understanding of identity allows us to avoid conceptualising identity as fixed categories (Somers, 1994).

Identity theories have been used extensively within research exploring (dis)engagement in STEM, particularly for those from backgrounds underrepresented in these fields. The papers that we found that used identity theories in a STEAM context also focussed on this phenomenon. Avendano-Uribe et al. (2022) included identity as part of a conceptual framework to investigate how STEAM 'maker projects' allow students to develop modes of belonging within their rural and remote communities. Claville et al. (2019) and Full et al. (2021) were similarly interested in 'science identity' as a variable of interest to explore persistence in STEM careers when evaluating a STEAM intervention with school and university students. By removing artificially created disciplinary boundaries (Full et al., 2021), STEAM practices that use identity theories can engage in a more authentic exploration of the relationality between identity formation and the diverse range of relata inherent in social contexts.

6. Discussion

While STEAM education continues to be an exciting and growing field, several gaps have been identified, particularly around the lack of a solid and comprehensive conceptual base for STEAM research. This ambiguity has ranged from how STEAM itself is conceptualised to the often implicit use of theories within its practice, leading to limited

criticality in conclusions (Colucci-Gray et al., 2017). Furthermore, while there is extant evidence of the cognitive, aesthetic, and academic benefits of arts education, it is argued that the same evidence does not yet exist for STEAM (Perignat & Katz-Buonincontro, 2019).

The use of theory provides explanatory power to research, making connections between phenomena and emphasising the nature of causal relationships (Sutton & Staw, 1995). As Stephen Ball (2006) argues, theory allows us to be made 'uncomfortable'. Theory challenges traditional and potentially oppressive modes of thinking and seeing the world, leading to emancipation and transformation for marginalised or underrepresented groups. As a reflexive tool, theory can prevent researchers becoming complacent or reductive in their readings of social subjectivities. It stops us from being too 'hasty' and allows us to 'slow down'. Such principles are seemingly intrinsic to STEAM, and yet, as noted in this paper, it is often absent in publications on STEAM practice. Only 56% of the 87 papers that fit our inclusion and exclusion criteria referred to a theory or construct. For the remaining papers, there were often limitations in its application—either due to a lack of methodological robustness (e.g., it is defined but then its application to the STEAM practice is not effectively described or discussed) or because there was no attempt to connect the theory to STEAM.

The discrepancies in the use of theory may be explained by the fledgling nature of the 'STEAM' field, highlighting the need for a systematically developed 'classification system' that can provide researchers and practitioners with a tool to navigate the diverse range of theoretical frameworks available. The few other existing frameworks incorporate practical rather than theoretical aspects of STEAM integration in formal education settings, e.g., Ng et al. (2022) and Tasiopoulou et al. (2022). Others, e.g., Ussher et al. (2023) and Rodrigues-Silva and Alsina (2023), take a more evaluation-based approach, considering STEAM activities based on a range of competencies or conditions. The classification system here is, we believe, the first of its kind to map and classify the epistemological potential for STEAM.

A priori theory is central to praxis-oriented research (Lather, 1986). However, knowing where to start can be challenging. Users of our proposed classification system can, depending on the perspective of a STEAM project (be it 'experiential real-world interactions', 'human psychological and cognitive', 'social, spatial, and material interconnectivity', or 'cultural and equity'), select one of the theories or conceptual frameworks situated within the favoured approach as the beginning 'stepping stones' to provide explanations and to interrogate the validity of these explanations (Moulaert et al., 2013). In turn, these explanations can assist with the development of practice and further contextual theorising, leading to impactful, emancipatory STEAM praxis that challenges 'conservative orthodoxies' (Ball, 2006).

While the classification system in this paper provides an epistemological mapping to understand STEAM processes, effects, and ways of being in a particular STEAM area, it also offers the framing of a relational ontology as a fundamental aspect. Relationality refutes arbitrary boundaries that can disrupt effective and authentic STEAM practice. This argument for a relational lens to reality therefore gives the classification system the potential power to counter disciplinary and individual siloing for its own sake and to foreground productive relations in the face of real-world problems. It acknowledges the 'active connectivity' (Hoffmann & Peeren, 2015) in relations between disciplines, between collaborating learners, and between the learner and the 'real world', specifically between learners and 'other-than-learners' (contexts, activities, practices, materials, nature, etc.)—crucially decentring humans to foreground STEAM relations, rather than the relata, to engage in more equitable, critical Anthropo-eco-centrism (Chappell & Ben-Horin, 2023). Using a relational ontology in conjunction with their chosen framework should prompt researchers to consider the relations between the relata of their STEAM practice, rather

than focusing on the subjects of their practice, in order to take a more holistic view to understand its impact.

We acknowledge that a relational ontology, whilst active within all four approaches, works to varying degrees within each approach. In our analysis, we have discussed how human psychological and cognitive approaches tend to focus on the individual mind. There is recognition of the importance of collaboration in cognitive psychology methodologies, but perhaps there is also a question raised here about the appropriateness of using theories that fall under this banner to provide an understanding of STEAM practice. We developed the classification system reported in this paper based on a literature review of the breadth of onto-epistemological frameworks in existing STEAM research, and the four approaches outlined in this paper offer some insight into the different paradigms that are used across educational, philosophical, and social science research. The four approaches are in themselves relata, and the relations between them are dynamic and complex. Future work can explore in greater depth the nature of the relations between these approaches.

Crucially, our classification system does not value one approach or individual framework over another. It therefore does not prioritise the largely positivist frameworks found within cognitive research, which are perhaps more dominant in STEAM studies due to a historical tendency in particular disciplines to favour these methodologies. By removing hierarchies in the approaches and frameworks, we aim to offer space for all onto-epistemological and axiological positions. In so doing, we suggest that the time is now right for greater critical reflection as to the appropriateness of the epistemologies and ontologies of dominant methodologies, with an emphasis on creating space for others to be applied that may be more relevant to relational STEAM practices in different educational settings. In part, this is about raising awareness that these other approaches exist as theoretical options, which can and need to be judged by rigorous standards of their own.

As noted above, STEAM is an emerging field; we anticipate that additional frameworks will be drawn upon in future research—for example, constructivism may be expanded to 'constructivist approaches'. Furthermore, we acknowledge that the use of inclusion and exclusion criteria from the Road-STEAMer project's parameters around secondary–tertiary transitions, open science, and open schooling will have impacted our findings. For example, while our analysis identified limited theoretical application in the studies that we found that took a design-thinking approach, this is not to say that design thinking does not belong in a theoretical classification system for STEAM. While our search criteria, in some ways, can be said to have limited the resulting framework(s), these parameters offer clear guidelines for applicability that do not overclaim relevance across all STEAM education practices per se, which we argue is an almost impossible task. Similarly, the time-specific nature of our searches should be noted. We do not claim to have covered all theoretical frameworks in STEAM, and we wish to note that not all of the literature used theory effectively or rigorously. Nevertheless, our classification system benefits from being flexible. It is possible that we will add new approaches, or adapt the existing ones, in the future, as might others who engage with and develop the system. What we are offering with our classification system is a starting point from an applied perspective, seeking to provoke a discussion around the use (and lack of use) of theory in STEAM research.

STEAM was considered a borderline practice as recently as 2021 (Graham, 2021). The classification system presented here centralises STEAM as a practice and places the arts in equal position to STEM subjects. There are broader discussions regarding the need for the arts to be perceived as having as high a status as STEM and to push back against the idea that the arts' role in STEAM is to display or communicate the sciences (Katz-Buonincontro, 2018) or to act as a 'transversal creative component' for the STEM disciplinary model (Montés et al., 2024). Certainly, the understanding of disciplinary inter-relations within

the Road-STEAMer project acknowledges that students might move between disciplines (Dredd et al., 2021), that they might make new connections between subjects or skill areas within STEAM (Colucci-Gray et al., 2017; Johnson-Green et al., 2020) or form interactions between disciplines (Liu & Wu, 2022) or transfer knowledge between disciplines (Huser, 2020). Opening our understanding to these various inter-relations is another key role for this new classification system.

In relation to the implications of this new classification system for policy and practice, it is advantageous that this theoretical work has been carried out as part of a larger project designed to inform EU policy-setting agenda. Alongside impacts for academics, the system therefore has clear avenues via which it can influence future policy (e.g., Addis et al., 2023). This classification system is intended to be utilised by STEAM practitioners to analyse 50 case studies of STEAM practices, so that experts can begin to critically explore how an understanding of background theoretical framing can assist them to develop practice and achieve transformative aims.

We argue that this final point is crucial for the field moving forward. Returning to Lather's (1986) treatise on praxis, we must first know reality before we—practitioners and participants—can transform it. Indeed, the research process itself should 'reorient, focus and energise participants' (p. 272) towards this knowledge and transformation. This is how praxis achieves its emancipatory ends. This is the true impact of STEAM. In our review of the STEAM literature, it often seemed to be assumed that, by virtue of being STEAM, STEAM practice is good practice. It is our contention that STEAM *praxis* is good practice.

7. Conclusions

This study developed a classification system of STEAM epistemologies, derived from the literature exploring practice that bridges open science and open schooling within the transition between secondary and tertiary education. The system offers a relational ontology as a critical framing of STEAM practice, underpinning four approaches that acknowledge the breadth and range of methodologies and frameworks used across the social sciences. The approaches 'experiential real-world interactions', 'human psychological and cognitive', 'social, spatial, and material interconnectivity', and 'cultural and equity' are positioned alongside one another, rather than ranked in a hierarchical structure. This reinforces the relationality of the overall system and promotes equity among methodologies and disciplines. We consider this classification system to be flexible and hope that others will continue to adapt and develop the approaches to ensure that it remains an effective tool for robust, engaging, innovative, and emancipatory STEAM praxis.

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Appendix A

Citation	Title	Place of Publication	Theoretical Framework(s)	Approaches
Avendano-Uribe et al. (2022)	Resourcefulness, narratives, and identity in science, technology, engineering, arts and mathematics education: A perspective of makerspaces for rural communities in Colombia	*Frontiers in Education*	Identity Theory; Resourcefulness; Narratives	Cultural and Equity Approaches; Human Psychological and Cognitive Approaches
Bass et al. (2016)	Designing the Game: How a Project-Based Media Production Program Approaches STEAM Career Readiness for Underrepresented Young Adults	*Journal of Science Education & Technology*	Connected Learning	Social, Spatial, Material Interconnectivity Approaches
Boice et al. (2021)	Supporting Teachers on Their STEAM Journey: A Collaborative STEAM Teacher Training Program	*Education Sciences*	Self-Efficacy; Social Network Theory	Human Psychological and Cognitive Approaches; Social, Spatial, Material Interconnectivity Approaches
Caratozzolo et al. (2021)	Fostering Digital Literacy through Active Learning in Engineering Education	*IEEE Frontiers in Education Conference Proceedings*	Active Learning	Experiential Real-World Interactions approaches; Human Psychological and Cognitive Approaches
Chang et al. (2019)	The Influence of Interactive Art of Visual Music on the Creativity of Science and Engineering Students	*IEEE Global Engineering Education Conference Proceedings*	Torrance Tests of Creativity	Human Psychological and Cognitive Approaches
Chappell et al. (2023)	Re-Creating Higher Education Pedagogy by Making Materiality and Spatiality Matter	*The Journal of Creative Behavior*	Transdisciplinarity and Creativity through Spatiality and Materiality	Social, Spatial, Material Interconnectivity Approaches
Chen and Lo (2019)	From Teacher-Designer to Student-Researcher: a Study of Attitude Change Regarding Creativity in STEAM Education by	*Journal for STEM Education Research*	Creative Thinking	Human Psychological and Cognitive Approaches

	Using Makey Makey as a Platform for Human-Centred Design Instrument			
Chung and Li (2021)	Issues-Based STEAM Education: A Case Study in a Hong Kong Secondary School.	*International Journal of Education & the Arts*	Critical Pedagogy	Cultural and Equity Approaches
Claville et al. (2019)	NanoHU: A Successful Collaborative STEM Model Preparing African Americans for Engagement in Nanoscience, Laying the Foundation for Transformative, Institutional Steam Engagement	*Diversity in Higher Education*	Identity Theory	Cultural and Equity Approaches
Costantino (2017)	STEAM by another name: Transdisciplinary practice in art and design education	*Arts Education Policy Review*	Creative Inquiry for Transdisciplinarity	Experiential Real-World Interactions Approaches
Davies and Trowsdale (2021)	The culture of disciplines: reconceptualising multi-subject curricula	*British Educational Research Journal*	Space–Time and Culture	Social, Spatial, Material Interconnectivity Approaches; Cultural and Equity Approaches
Del Valle-Morales et al. (2020)	Use of Emerging Conductive Materials for K-12 STEAM Outreach Activities and the Impact on Community Education Resilience.	*IEEE Resilience Week Conference Proceedings*	Bloom's Learning Taxonomy; Resilience	Human Psychological and Cognitive Approaches; Human Psychological and Cognitive Approaches
DeVito et al. (2020)	Culturally Responsive Research Projects in a Title I Elementary Center for Fine Arts	*Visions of Research in Music Education*	Culturally Responsive Pedagogy	Cultural and Equity Approaches
Domenici (2022)	STEAM Project-Based Learning Activities at the Science Museum as an Effective Training for Future Chemistry Teachers	*Education Sciences*	Constructivism	Experiential Real-World Interactions Approaches
Dredd et al. (2021)	Zen and the Art of STEAM: Student Knowledge and Experiences in Interdisciplinary and	*IEEE Frontiers in Education Conference Proceedings*	Flow State	Human Psychological and Cognitive Approaches; Social, Spatial, Material

	Traditional Engineering Capstone Experiences			Interconnectivity Approaches
Fletcher and Hernandez-Gantes (2021)	They're Moving in Spaces They're Not Used to: Examining the Racialized Experiences of African American Students in a High School STEAM Academy	*Education and Urban Society*	Critical Pedagogy; Social Justice Pedagogy	Cultural and Equity Approaches
Full et al. (2021)	Eyes Toward Tomorrow Program Enhancing Collaboration, Connections, and Community Using Bioinspired Design	*Integrative and Comparative Biology*	Self-Efficacy; Identity Theory	Human Psychological and Cognitive Approaches; Cultural and Equity Approaches
Guyotte (2020)	Toward a Philosophy of STEAM in the Anthropocene	*Educational Philosophy and Theory*	Affirmative Ethics; Slowing	Social, Spatial, Material Interconnectivity Approaches
Harris and de Bruin (2017)	Secondary school creativity, teacher practice and STEAM education: An international study	*Journal of STEM Education: Innovations & Research*	Five Creative Dispositions Model	Human Psychological and Cognitive Approaches
Kant et al. (2018)	Engaging High School Girls in Native American Culturally Responsive STEAM Enrichment Activities	*Innovative Technologies and Learning: Third International Conference Proceedings*	Culturally Responsive Pedagogy	Cultural and Equity Approaches
Kiyani et al. (2020)	Designing Freirean-inspired community relevant steam curriculum for underserved students in Pakistan using action research process	*ICITL Conference Proceedings*	Critical Pedagogy	Cultural and Equity Approaches
Mehta et al. (2019)	Developing a rhetoric of aesthetics: The (often) forgotten link between art and STEM	*STEAM Education: Theory and Practice*	Aesthetics	Experiential Real-World Interactions Approaches
Peppler and Wohlwend (2018)	Theorizing the nexus of STEAM practice	*Arts Education Policy Review*	Nexus Theory	Social, Spatial, Material Interconnectivity Approaches
Quigley et al. (2019)	Moving toward transdisciplinary instruction: A longitudinal examination of STEAM teaching practices	*STEAM Education: Theory and Practice*	Social Practice Theory	Social, Spatial, Material Interconnectivity Approaches

Rao et al. (2021)	Building Teacher Community during a Summer of Crisis: STEAM Professional Development in 2020	*Journal of STEM Outreach*	Culturally Responsive Pedagogy	Cultural and Equity Approaches
Stroud and Baines (2019)	Inquiry, investigative processes, art, and writing in STEAM	*STEAM Education: Theory and Practice*	Dewey/Learning through Experience	Experiential Real-World Interactions Approaches

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