REVISITING STEAM IN THE INTERPLAY BETWEEN EXTRINSIC AND INTRINSIC GOALS OF EDUCATION: IMPLICATIONS FOR TEACHING AND TEACHER TRAINING

Jefferson Rodrigues-Silva

DOCTORAL THESIS

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Jefferson Rodrigues da Silva

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Supervised by:
Dr. Àngel Alsina Pastells

Presented to obtain the degree of PhD at the University of Girona

Dr Ángel Alsina Pastells, Full Professor of Mathematics Education at the University of Girona.

I DECLARE,

That the thesis titles "Revisiting STEAM in the interplay between extrinsic and intrinsic goals of education: Implications for teaching and teacher training", presented by Jefferson Rodrigues da Silva to obtain a doctoral degree, has been completed under my supervision and meets the requirements to opt for an International Doctorate.

For all intents and purposes, I hereby sign this document.

Signature

Girona, 2023

If men were not distinct, each human being distinguished from any other who is, was, or will ever be, they would need neither speech nor action to make themselves understood.

Hannah Arendt.

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LIST OF ABBREVIATIONS

ABD: Aprendizaje Basado en Diseño

ABP: Basado en Proyectos

AIDS: Acquired immunodeficiency syndrome

ANOVA: Analysis of variance

ARPA: Activando la Resolución de Problemas en las Aulas

CEM: Competencias Específicas Matemáticas

DAET: Draw an Engineer Test

DAST: Draw a scientist Test

DESA: Department of Economic and Social Affairs

DOI: Digital Object Identifier

ECE: Early Childhood Education

ECEfS: Early Childhood Education for Sustainability

EDS: educación para el desarrollo sostenible

EfS: Education for Sustainability

EPSD: European Panel on Sustainable Development

ERIC: Education Resources Information Center

Est: Student

IBL: Inquiry-Based Learning

IFMG: Federal Institute of Education, Science and Technology of Minas Gerais

KOFAC: Korea Foundation for the Advancement Science & Creativity

mDAET: modified Draw an Engineer Test

MEFP: Ministerio de Educación y Formación Profesional

NCTM: National Council of Teachers of Mathematics

NGSS: Next Generation Science Standards

NSF: National Science Foundation

ODS: Objetivo del Desarrollo Sostenible

OECD: Organization for Economic Cooperation and Development

PBL: Problem-Based Learning

PjBL: Project-Based Learning

PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses

SDG: Sustainable Development Goal

SPSS: Statistical Package for the Social Sciences

STEAM: Science, Technology, Engineering, Arts/Humanities, and Mathematics

STEM: Science, Technology, Engineering, and Mathematics

TO: Theatre of the Oppressed

UdG: University of Girona

UNESCO: United Nations Educational, Scientific, and Cultural Organization

USA: United States of America

USSR: Union of Soviet Socialist Republics

WCRD: World Commission on Environment and Development

WoS: Web of Science

ABSTRACT

STEM was coined in 1990, referring to the interdisciplinarity between science, technology, engineering, and mathematics. Approximately two decades later STEAM emerged as a new acronym, including arts and humanities. While STEAM has gained recognition in educational research and practice, it has also faced criticism for being limited to qualification purposes, such as enhancing creativity for problem-solving in specific careers.

Considering non-consensual understandings, we aim to revisit STEAM exploring its distinctiveness as an educational approach embedded within the broader discourses of education and tensions between the extrinsic and intrinsic educational goals. For that, we embarked on an article-based doctoral thesis utilising mixed-method research across three phases of knowledge development: 1) problem conceptualisation, 2) empirical investigation, and 3) implementation and evaluation.

The problem conceptualisation phase comprises five articles on qualitative methods: concept analysis, narrative reviews and systematic reviews. These articles delve into STEAM epistemology, exploring its connections with sustainability and playful learning. The empirical investigation phase consists of two mixed-method articles. One quasi-experimental study inquires about students' conceptions of engineering, and a second case study examines the effects of a practical teacher-training programme on planning STEAM ability. Finally, the implementation and evaluation phase concerns two qualitative articles describing STEAM activities on engineering teaching, first intertwined with sustainability and then playful drama, representing extrinsic and intrinsic goals of education.

As a result, we provided a concise definition of STEAM stressing two necessary and sufficient conditions—interdisciplinarity and the five acronym areas. We highlighted the appropriateness of interdisciplinarity (instead of transdisciplinarity) while recovering teaching as fundamental to strengthening knowledge and hindering stereotypical conceptions of the disciplines and their intersections. Following those ideas, we evidenced that teacher training helps to improve planning STEAM activity abilities. Additionally, we exemplified how STEAM can conciliate extrinsic and intrinsic goals of education, such as sustainability and

playful learning, into teaching practices that promote a well-rounded educational experience involving qualification, socialisation and subjectification.

RESUMEN

El término STEM fue acuñado en 1990 para referirse a la interdisciplinariedad entre ciencia, tecnología, ingeniería y matemáticas. Aproximadamente dos décadas más tarde surgió STEAM como un nuevo acrónimo que incluía las artes y las humanidades. Aunque STEAM ha ido ganando reconocimiento en la investigación y la práctica educativa, también ha sido criticado por limitarse a fines de cualificación, como potenciar la creatividad para la resolución de problemas en carreras específicas.

Teniendo en cuenta las interpretaciones no consensuadas, se pretende revisar la conceptualización de STEAM explorando su carácter distintivo como enfoque educativo y desde discursos más amplios de la educación, como las tensiones entre las demandas extrínsecas de la sociedad y los objetivos educativos intrínsecos. Para ello, se ha desarrollado una tesis doctoral por compendio de artículos desde un abordaje metodológico mixto y considerando tres fases de desarrollo del conocimiento en investigación educativa: 1) definición del problema, 2) investigación empírica y 3) aplicación y evaluación.

La fase de definición del problema comprende cinco artículos basados en métodos cualitativos: análisis conceptual, revisiones narrativas y sistemáticas. Estos artículos profundizan en la epistemología STEAM, explorando sus conexiones con la sostenibilidad y el aprendizaje lúdico. Seguidamente, la fase de investigación empírica consta de dos artículos basados en métodos mixtos: un estudio cuasi-experimental que indaga sobre las concepciones del alumnado de primaria acerca de la ingeniería, y un estudio de caso que examina los efectos de un programa práctico de formación de profesores sobre la habilidad para planificar actividades STEAM. Por último, la fase de aplicación y evaluación incluye dos artículos de naturaleza cualitativa que describen actividades STEAM: el primero, sobre la enseñanza de la ingeniería en conexión con la sostenibilidad, representa los objetivos extrínsecos de la sociedad; mientras que el segundo, que conecta la ingeniería con el teatro como actividad lúdica, representa objetivos intrínsecos de la educación.

A partir de estos estudios, se (re)conceptualiza de manera concisa STEAM desde dos condiciones necesarias y suficientes: la interdisciplinariedad y las cinco áreas del acrónimo. Se destaca la adecuación de la interdisciplinariedad (en lugar de la transdisciplinariedad)

mientras se recupera la enseñanza como fundamental para fortalecer el conocimiento y evitar concepciones estereotipadas sobre las disciplinas y sus intersecciones. Con base en estos planteamientos, se evidencia que la formación del profesorado ayuda a mejorar las habilidades de planificación de actividades STEAM. Además, se ejemplifica cómo STEAM puede conciliar objetivos extrínsecos e intrínsecos de la sociedad y la educación respectivamente, como la sostenibilidad y el aprendizaje lúdico, en prácticas de enseñanza que promuevan una experiencia educativa integrada que involucre cualificación, socialización y subjetivación.

RESUM

STEM va emergir l'any 1990 per referir-se a la interdisciplinarietat entre ciència, tecnologia, enginyeria i matemàtiques. Aproximadament dues dècades més tardva sorgir STEAM com un nou acrònim que incloïa les arts i les humanitats. Encara que STEAM ha anat guanyant reconeixement en la recerca i la pràctica educativa, també ha estat criticat per limitar-se a finalitats de qualificació, com ara potenciar la creativitat per a la resolució de problemes en carreres específiques.

Tenint en compte les interpretacions no consensuades, es pretén revisar la conceptualització de STEAM explorant el seu caràcter distintiu com a enfocament educatiu i des de discursos més amplis de l'educació, com les tensions entre les demandes extrínseques de la societat i els objectius educatius intrínsecs. Tenint en compte aquest propòsit, s'ha desenvolupat una tesi doctoral per compendi d'articles des d'una perspectiva metodològica mixta i considerant tres fases de desenvolupament del coneixement en recerca educativa: 1) definició del problema, 2) recerca empírica i 3) aplicació i avaluació.

La fase de definició del problema comprèn cinc articles basats en mètodes qualitatius: anàlisi conceptual, revisions narratives i sistemàtiques. Aquests articles aprofundeixen en l'epistemologia STEAM, explorant les seves connexions amb la sostenibilitat i l'aprenentatge lúdic. Seguidament, la fase de recerca empírica consta de dos articles basats en mètodes mixtos: un estudi quasi-experimental que indaga sobre les concepcions de l'alumnat de primària sobre l'enginyeria, i un estudi de cas que examina els efectes d'un programa pràctic de formació de professors sobre l'habilitat per a planificar activitats STEAM. Finalment, la fase d'aplicació i avaluació inclou dos articles de naturalesa qualitativa que descriuen activitats STEAM: el primer, sobre l'ensenyament de l'enginyeria en connexió amb la sostenibilitat, representa els objectius extrínsecs de la societat; mentre que el segon, que connecta l'enginyeria amb el teatre com a activitat lúdica, representa objectius intrínsecs de l'educació.

A partir d'aquests estudis, es (re)conceptualitza de manera concisa STEAM des de dues condicions necessàries i suficients: la interdisciplinarietat i les cinc àrees de l'acrònim. Es destaca l'adequació de la interdisciplinarietat (en lloc de la transdisciplinarietat) mentre es

recupera l'ensenyament com a fonamental per a enfortir el coneixement i evitar concepcions estereotipades sobre les disciplines i les seves interseccions. Amb base en aquests plantejaments, s'evidencia que la formació del professorat ajuda a millorar les habilitats de planificació d'activitats STEAM. A més, s'exemplifica com STEAM pot conciliar objectius extrínsecs i intrínsecs de la societat i l'educació respectivament, com la sostenibilitat i l'aprenentatge lúdic, en pràctiques d'ensenyament que promoguin una experiència educativa integrada que involucri qualificació, socialització i subjectivació.

LIST OF PUBLICATIONS[1]

This doctoral thesis has an article-based format. It means the thesis compiles published, accepted, and submitted articles.

Published or accepted articles

Article 1. Conceptualising and framing STEAM education: What is (and what is not) this educational approach?.. 55

Digital Object Identifier (DOI) link: Article in press

Journal: *Texto Livre – Linguagem e Tecnologia* (ISSN 1983-3652)

Publisher: Federal University of Minas Gerais

Country: Brazil

Indexed in: Web of Science, Scopus, Latindex, Periodicos da CAPES, Fuente Academica Plus, DIALNET, DOAJ, Modern Language Association Database (MLA).

Metrics: Emerging Sources Citation Index (ESCI): JCI = 0.53 (2nd quartile); Scimago Journal & Country Rank (SJR) = 0.14 (3rd quartile); Qualis CAPES (triennium 2017–2020) = A1

[1] The information presented about the journals was mainly extracted from the website of Information Matrix for the Analysis of Journals (MIAR). Complementarily, Journals' metrics were consulted on the corresponding index platforms on 1st May: Emerging Sources Citation Index (ESCI) and Social Sciences Citation Index (SSCI) were extracted from Journal Citation Report (JCR); Scimago Journal & Country Rank (SJR) was extracted from Scimago; Qualis CAPES (triennium 2017–2020) was extracted from Sucupira plataform; and Latindex accomplished characteristics were extracted from Latindex Catalogue.

Article 3. STEM/STEAM in Early Childhood Education for Sustainability (ECEfS): A systematic review 105

Digital Object Identifier (DOI): 10.3390/su15043721

Journal: Sustainability (ISSN 2071-1050)

Publisher: Multidisciplinary Digital Publishing Institute (MDPI)

Country: Switzerland

Indexed in: Web of Science, Scopus, DOAJ, Aerospace Database, Agricultural & Environmental Science Database, CAB Abstracts, Civil Engineering Abstracts, Food Science & Technology Abstracts, INSPEC, Metadex, Veterinary Science Database, Communication Abstracts, Geobase

Metrics: Social Sciences Citation Index (SSCI): JIF = 3.89 and JCI = 0.65 (2nd quartile); Scimago Journal & Country Rank (SJR) = 0.66 (1st quartile); Qualis CAPES (triennium 2017–2020) = A2

Article 4. STEAM education and playful learning at all educational levels (*La educación STEAM y el aprendizaje lúdico en todos los niveles educativos*) 129

Digital Object Identifier (DOI): 10.25112/rpr.v1.3170

Journal: Prâksis (ISSN 2448-1939)

Publisher: Feevale University

Country: Brazil

Indexed in: Scopus, Latindex, Periódicos da CAPES, Redalyc, Ebsco, Redib, Erihplus, DOAJ, Road, Icap,

Metrics: Scimago Journal & Country Rank (SJR) = 0.1 (4th quartile); Qualis CAPES (triennium 2017–2020) = B3

Article 5. Systematic review about students' conceptions of engineering accessed through drawings: Implications to STEAM education 157

Digital Object Identifier (DOI) link: Article in press

Journal: International journal of cognitive research in science, engineering and education (ISSN 2334-8496)

Publisher: The Association for the Development of Science, Engineering and Education, Serbia

Country: Serbia

Index: Scopus, Emerging Sources Citation Index, Academic Search Premier, DIALNET, DOAJ, Central & Eastern European Academic Source (CEEAS)

Main metric: Scimago Journal & Country Rank (SJR) = 0.35 (3rd quartile)

Article 6. Students' conceptions of engineering and its connections with mathematics and science (*Concepciones del alumnado sobre ingeniería y sus conexiones con las matemáticas y las ciencias*) 179

Digital Object Identifier (DOI) link: Article in press

Journal: Enseñanza de las Ciencias (ISSN 2174-6486)

Publisher: Autonomous University of Barcelona

Country: Spain

Index: Web of Science, Scopus, DIALNET, DOAJ, Psycinfo.

Main metrics: Social Sciences Citation Index (SSCI): JIF = 2.22 (4th quartile) and JCI = 0.63; Scimago Journal & Country Rank (SJR) = 0.50 (2nd quartile); Qualis CAPES (triennium 2017–2020) = A1

Article 7. Effects of a practical teacher-training program on STEAM activity planning 211

Digital Object Identifier (DOI): 10.20952/revtee.v15i34.17993

Journal: Revista Tempos e Espaços Educação (ISSN 1983-6597)

Publisher: Federal University of Sergipe

Country: Brazil

Indexed in: Web of Science, Latindex, Periódicos da Capes, DOAJ, Edubase, DIALNET, Diadorim, Redib

Metrics: Emerging Sources Citation Index: JCI = 0.26 (4th quartile); Latindex: 33 accomplished characteristics; Qualis CAPES (triennium 2017–2020) = A3

Article 8. Putting engineering on the table: A STEAM activity of reverse engineering and mathematics (*Poniendo la ingeniería sobre la mesa: una actividad STEAM de ingeniería inversa y matemática*) 229

Digital Object Identifier (DOI) link: Article in press

Journal: Pesquisa e Debate em Educação (ISSN 2237-9444)

Publisher: Federal University of Juiz de Fora

Country: Brazil

Indexed in: DOAJ, Latindex, Periódicos da Capes, ERIHPlus

Main metrics: Latindex: 34 accomplished characteristics; Qualis CAPES (triennium 2017–2020) = B1

Submitted articles

Article 2. STEAM embedded in tensions and homogeneous discourses of education 77

Journal: Revista Educação em Questão (ISSN 1981-1802)

Publisher: Federal University of Rio Grande do Norte

Country: Brazil

Indexed in: Latindex, Periodicos da CAPES, IRESIE, DIALNET, DOAJ, REDIB

Metrics: Latindex. Catalogue v1 (2002 - 2017): 34 accomplished characteristics; Qualis CAPES (triennium 2017–2020) = A1.

Article 9. STEAM and theatrical education: When engineering students play a role................. 251

Journal: Dialogia (ISSN 1983-9294)

Publisher: Universidade Nove de Julho

Country: Brazil

Main index: Emerging Sources Citation Index, Academic Search Premier, Fuente Academica Plus.

Main metrics: Emerging Sources Citation Index: JCI = 0.06 (4th quartile); Qualis CAPES (triennium 2017–2020) = A4

INTRODUCTION

In this chapter, we define the scope of the study and formulate a research question. Subsequently, we establish the overarching research goal of the thesis and scrutinise it into specific objectives. Additionally, we indicate the articles compiled in this thesis, considering their contributions to each objective.

1.1. Problem definition and research question

Over the past two decades, educational policies have summoned educators to embrace a new approach to the disciplines of STEM, referring to Science, Technology, Engineering, and Mathematics (Catterall, 2017). At the core of these callings underlies the urge to approximate the education provided in schools and the needs of contemporary society (Quigley et al., 2020). Accordingly, such an arrangement emphasises the flourishment of students' abilities apparently compatible with twenty-first-century citizenship (Chen et al., 2023).

Following these ideas, the National Science Foundation (NSF) coined the acronym STEM in the 90s (Catterall, 2017; Perignat & Katz-Buonincontro, 2019) to denote policies and justify the investment focused on qualifying professionals of the technical areas comprising the acronym (Chesky & Wolfmeyer, 2015). Since its creation, independent of whether expressing any disciplinary integration, STEM has been applied as a generic label to report practices involving one or more of its constituents (Ortiz-Revilla et al., 2020).

Alongside this mere listing of disciplines, practitioners and researchers have resignified STEM into a pedagogy of interdisciplinarity—or transdisciplinary to some—of those knowledge areas (Couso, 2017; Kelley & Knowles, 2016; Ortiz-Revilla et al., 2021; Quigley et al., 2020). In 2007, amidst discontent with the privileged attention on technical areas, the acronym STEAM was formalised at the Americans for the Arts-National Policy Roundtable by including the letter A for the Arts (Perignat & Katz-Buonincontro, 2019). Afterwards, some researchers defend further broadening the scope of STEAM by encompassing Arts and Humanities (Garza, 2021; López et al., 2021).

Since their formalisation, STEM and STEAM have progressed in research and practice. Countries such as the USA, Korea, and Spain have embraced STEM or STEAM into their curriculums (KOFAC, 2013; MEFP, 2022; NGSS, 2013). As evidence, bibliometric analyses show these educational approaches are prominently growing as research lines (Marín-Marín et al., 2021; Zhao, 2023). Interestingly, analysis based on big data concluded that STEAM is in its infancy compared to STEAM. However, STEAM has exhibited a higher growth rate in the last six years (Zhao, 2023).

STEM and STEAM incorporated dominant educational discourses associated with the transition from policy to pedagogy. Accordingly, these approaches are frequently oriented toward the socio-constructivist paradigm, following claims such as active, collaborative, authentic, and meaningful learning (Schlesinger et al., 2020). At the same time as entering education, researchers have revisited those educational approaches pursuing epistemological enlightenment while scrutinising "value-neutral tenets" (Ortiz-Revilla et al., 2020, p. 862).

For example, Mariano and Chiappe (2021) reviewed "twenty-first-century skills" associated with STEAM publications. The authors observed an empty discourse by stating that "[t]he definition of the term 21st-century skills is currently very difficult to make as many authors, governments and organisations have been using the term indistinctively to refer to whatever they think it is proper to call as such". In this same vein, the straightforward claim for flourishing children's desirable abilities to become citizens adapted to the needs of a twenty-first-century society started to face examinations. From the prism of democratic education, for instance, critique wonder who is precisely that citizen, how this society is, which changes are worth adaptation and how to recognise them (Biesta, 2011).

In the middle of all this discussion, there is a sort of antagonism between society and education. While society feels legitimate to set agendas and check school results, education must withstand intrinsic purposes (*telos*) (Biesta, 2015b). As Biesta (2019) states, there is "a tension at the very heart of the modern school—a tension between the demand to be useful for society and a demand for keeping society at a distance' (p. 662). This last configuration is congruent with the idea that schools must shield off newcomers so they have time and space to grow before facing adult and political life (Arendt, 1958; Martins & Rodrigues-Silva, 2022). From this tension, it is possible to comprehend, for example, the bifurcation of

STEAM from STEM as a vivid debate on which disciplines should be integrated regarding extrinsic or intrinsic objectives of education.

Even though the instrumentalised conception of STEAM may persist in some policies, research, and practices (Chesky & Wolfmeyer, 2015; Mejias et al., 2021), within this doctoral thesis, we focus on STEAM aligned with humanistic concerns. In this regard, society may present legitimate intentions instead of restricting economic-driven demands. For example, the United Nations has called for the contribution of education to cultivate sustainable literacy and behaviour (UNESCO, 2005, 2008; United Nations, 2015). Moreover, they have specifically proposed STEAM as an appropriate pedagogy to achieve Sustainable Development Goals (SDG)(United Nations, 2018)—being sustainability understood as aiming balanced relationship between social, economic, and environmental spheres (Brundtland, 1987).

At the same time, as the society may present genuine demands such as sustainability, perhaps STEAM could withstand intrinsic educational goals while resisting being promptly worthwhile to society. For example, preserving playful learning despite the pressure that states play would waste children's time (Schlesinger et al., 2020).

Researchers vary on definitions and frameworks of STEAM education (Ortiz-Revilla et al., 2021; Perignat & Katz-Buonincontro, 2019). Literature often reports STEAM from pedagogical practices that are inherently specific to the conditions of each context (Marín-Marín et al., 2021). Essential STEAM aspects must be explored to determine the fundamentals that distinguish it as a proper educational approach. We argue that focused attention would shed light on topics of STEAM, such as incorporating technology and engineering—disciplines traditionally absent from precollege curriculums (Berciano et al., 2021; Moore et al., 2014).

Accordingly, it is necessary to understand STEAM in the breadth of education and how it is crossed through discourses and tensions permeating education. This comprehension may help determine which discussions are specific to STEAM and how broader educational discourses may affect it. In teacher training, for example, STEAM is frequently articulated from particular perspectives, such as robotics (Román-Graván et al., 2020), computational thinking (Pears et al., 2019), and climate change (Won et al., 2021). At the same time, central topics are overseen, such as incorporating engineering into the class, which is quite challenging for most teachers (Webb & LoFaro, 2020). Studies report that teachers struggle with planning STEAM activities, applying diverse teaching methods, and collaborating with peers (Boice et al., 2021). Specifically, despite teachers being recognised as critical actors in implementing STEAM education, few teacher training programmes have focused on developing teachers' planning STEAM ability (Marín-Marín et al., 2021). Eventually, teachers and researchers need examples of STEAM planned according to its essential aspects and embracing educational purposes beyond qualification.

Considering all that, we formulate the research question—how can STEAM be reconceptualised as an educational approach to elucidate its extrinsic and intrinsic goals and its implications for teaching and teacher training?

1.2. Objectives

Considering the study's scope and research question, we set this thesis's overarching goal. Accordingly, we aim to revisit STEAM exploring its distinctiveness as an approach in the interplay between extrinsic and intrinsic goals of education while underlining teaching and teacher training. In order to achieve this overarching goal, we have identified five specific research objectives. Thus, our aim is to:

OBJ1: Delve into the epistemology of STEAM by scrutinising its distinctiveness as a specific educational approach embedded in education.

OBJ2: Explore the connection between STEAM and the societal imperative for sustainability as an extrinsic goal of education.

OBJ3: Investigate the connection between STEAM and playful learning as a non-immediate social worthwhile goal.

OBJ4: Elaborate on the role of explicitly addressing the STEAM disciplines and their intersections to achieve intrinsic educational goals of education and mitigate stereotyped conceptions.

OBJ5: Assess the implications of a concise understanding of STEAM for teaching and teacher training.

Table 1 categorises the nine articles compiled in the thesis based on their contributions to the specific research objectives. Beyond an overview of their alignment with those objectives, this table (vertically) provides the interconnections within the articles. At this point, we emphasise the articles' main contributions. Further connections will be explored throughout the thesis, especially in the discussion and conclusions topic.

Table 1

Articles' contributions to the specific research objectives

Article	Research objective				
	OBJ1	OBJ2	OBJ3	OBJ4	OBJ5
ART1. Conceptualising and framing STEAM education	x			x	
ART2. STEAM embedded in tensions and homogeneous discourses of education*	x			x	
ART3. STEM/STEAM in Early Childhood Education for Sustainability (ECEfS)		x			
ART4. STEAM education and playful learning at all educational levels			x		
ART5. Systematic review about students' conceptions of engineering accessed through drawings				x	
ART6. Students' conceptions of engineering and its connections with mathematics and science				x	
ART7. Effects of a practical teacher-training program on STEAM activity planning					x
ART8. Putting engineering on the table		x			x
ART9. STEAM and theatrical education*			x		x

* The documents highlighted are under review, while the others are published or accepted for publication.

Note. Each research objective has at least one corresponding published or accepted article.

2. THEORETICAL SCAFFOLDING

In this chapter, we succinctly present the theoretical foundation of the thesis. As the compiled articles stand their own conceptual framework, we focused on aspects that help understand STEAM comprehensively and the interplay between extrinsic and intrinsic goals of education.

2.1. STEAM education

Since the beginning of modern science in the eighteenth century, bibliometric analyses show that scientific knowledge is growing at a rate that doubles every 17.3 years (Bornmann et al., 2021). According to Malone et al. (2011), epistemic complexity was successively accompanied by a phenomenon known as hyper-specialisation. Knowledge had to be separated into domains because it was no longer possible for a single person to understand all topics and tasks thoroughly. Indeed specialised knowledge effectively addresses precise subjects, contexts or applications. However, disciplinary fragmentation proved inefficient in encompassing complex problems (Danermark, 2019).

Beyond the accumulation of knowledge, interest in scientific and technical fields is escalating. The narrative of the commencement of a “STEM movement” usually is attributed to the USA as this country’s response triggered by the Sputnik-1 satellite being launched into orbit around the Earth (Perignat & Katz-Buonincontro, 2019). However, considering this same event, we should already deliberate that this movement occurred at least in one more region—the Union of Soviet Socialist Republics (USSR). Therefore, we reasonably endorse a temporally and spatially undetermined origin for the interest in scientific and technological areas.

Additionally, we acknowledge the precedents of this movement in educational history. Recalling that technological and scientific advancement played disastrous and central roles, for example, in the World Wars—from aeroplanes equipped with missiles to atomic bombs (Oliveira, 2022). In this regard, decades before the National Science Foundation (NSF) coined the term STEM; researchers promoted Science, Technology, and Society (STS), arguing for the need to expand historical and sociological perspectives on technoscientific knowledge (Fernandes et al., 2018; Ortiz-Revilla et al., 2020).

The USA was pivotal in funding, structuring, and popularising STEM education (Catterall, 2017). Accordingly, this country is the major contributor to publications about STEM and STEAM education (Zhao, 2023). At difference in STEM, perhaps, as educational changes require effort to surmount barriers and be implemented, the absence of a robust policy justifies the inconsistency of interdisciplinary movements such as STS (Ortiz-Revilla et al., 2020).

It is worth elucidating that disciplines are non-natural but virtually negotiated divisions of epistemological complexity (Danermark, 2019). Just like any discipline, the definitions of science, technology, engineering, arts/humanities, and mathematics are diffuse, overlapping and permanently being reconstructed. Notwithstanding, disciplines are comprehensible partitions of knowledge that permit its organisation and comprehension (Florentino & Rodrigues, 2015). Subsequently, we query the various forms of disciplines they can relate to each other. The word discipline is commonly accompanied by the prefixes *intra*, *cross*, *multi*, *inter* and *trans*.

- Intradisciplinary connects topics within the scope of the same discipline;
- Cross-disciplinary observes a topic of one discipline from the perspective of another;
- Multidisciplinary means that disciplines separately contribute to addressing a topic or problem;
- Interdisciplinarity integrates disciplines so that there is dialogue through them and their interspaces or intersections while addressing a topic or problem;
- Transdisciplinary addresses knowledge holistically to comprehend nature as it is—without delineating disciplines.

In interdisciplinarity, discipline borders are momentarily crossed to highlight their intersections. This way, disciplines are essential substrates that can be integrated through dialogue that provides understanding within and synergistically beyond the disciplines' original scope. Conversely, in transdisciplinarity, the focus remains on the problem without discerning individual disciplines and outlining intersections (Boufleuer & Moura, 2020; Florentino & Rodrigues, 2015).

Interdisciplinarity is another historically constructed epistemology (MacLeod, 2018). Ortiz-Revilla et al. (2020) defend the “seamless web” model for understanding the knowledge and practice in STEM disciplines. Those authors discuss the Family Resemblance Approach (FRA) to address the nature of science. In this context, FRA poses that different science disciplines have individual and general features. Subsequently, it is possible to establish categories, such as aims and values, practices, knowledge and social organisations, to arrange the disciples according to more similarities or differences (Cheung & Erduran, 2022). Scaffolded by such ideas, Ortiz-Revilla et al. (2020, p. 869) defend that education should highlight that “the frontiers between areas are blurred in the seamless web of STEM practices”. Ortiz-Revilla et al. (2020) suggest an alignment of STEM disciplines with sustainability while conserving their individual goals:

> Related to the aims and the values of integrated knowledge production in a seamless web of disciplines, the ultimate goal of the disciplines constituting the web of STEM should be the responsible resolution of relevant societal problems within a sustainability matrix. Such an idea would be within the core of the family resemblance between science, technology, mathematics and engineering. Each of these four constituents, in their turn, would have their own separate goals—the development of solutions, the understanding of nature, the production of machines, the design of processes, etc.—and any such goals could be discussed with students for their integral literacy (Ortiz-Revilla et al., 2020, p. 869).

Instead of searching the nature of such a thing as a “knowledge area STEAM”, we will further develop the distinctiveness of STEAM as an educational approach throughout the thesis. It is worth mentioning that this educational approach implies a curriculum modernisation introducing disciplines traditionally overseen at precollege levels—technology and engineering (Moore et al., 2014).

2.2. The interplay between extrinsic and intrinsic goals of education

We address STEAM in the breath of education through Gert Biesta's educational philosophy. Biesta is a recognised philosopher of education for questioning prevalent educational assumptions and practices. His philosophical orientation is described as critical and post-structuralist because he reassesses dominant discourses while emphasising the role of language, power, and social conceptions in influencing the understanding of education.

According to Biesta (2019), modern schools have a double history regarding the relationship between education and society. In the past, society had daily lives closely interwoven with work. In agricultural communities, for example, children could learn all they needed only by directly interacting with this daily life and work. Notwithstanding, as Biesta (2019) asserts, society loses its intrinsic educative power when work becomes more complex. From a certain point, newcomers cannot learn what they need by just experiencing daily life and work.

Consequently, a unique institution is required to prepare those children to participate in such societies— to qualify and socialise them in Biesta's terms. In this angle of history, education was created with a clear role of servitude toward society. Accordingly to this role, 'society has legitimate expectations towards the school' and a 'legitimate right to check whether the school is giving society what it wants from it' (Biesta, 2019, p. 661)

From another perspective of history, schools are spaces between private and public life that shield children from society's demands. This school arrangement is congruent with the idea that newcomers must have time and space to grow before facing adult and political life (Arendt, 1958). They need a safe environment that allows imagining, trying, making mistakes, and developing. In this setting, education does not have a subservient role toward society; instead, education intends to maintain a safe distance from it (Arendt, 1958; Biesta, 2016).

Biesta (2019) states that the referred double history of education culminates in a state of tension of demands. He says, 'there is a tension at the very heart of the modern school – a tension between the demand to be useful for society and a demand for keeping society at a distance.' (p. 662). Furthermore, protecting education from society's demands entails having a telos (*τέλος)* in Greek, which means purposes and agendas.

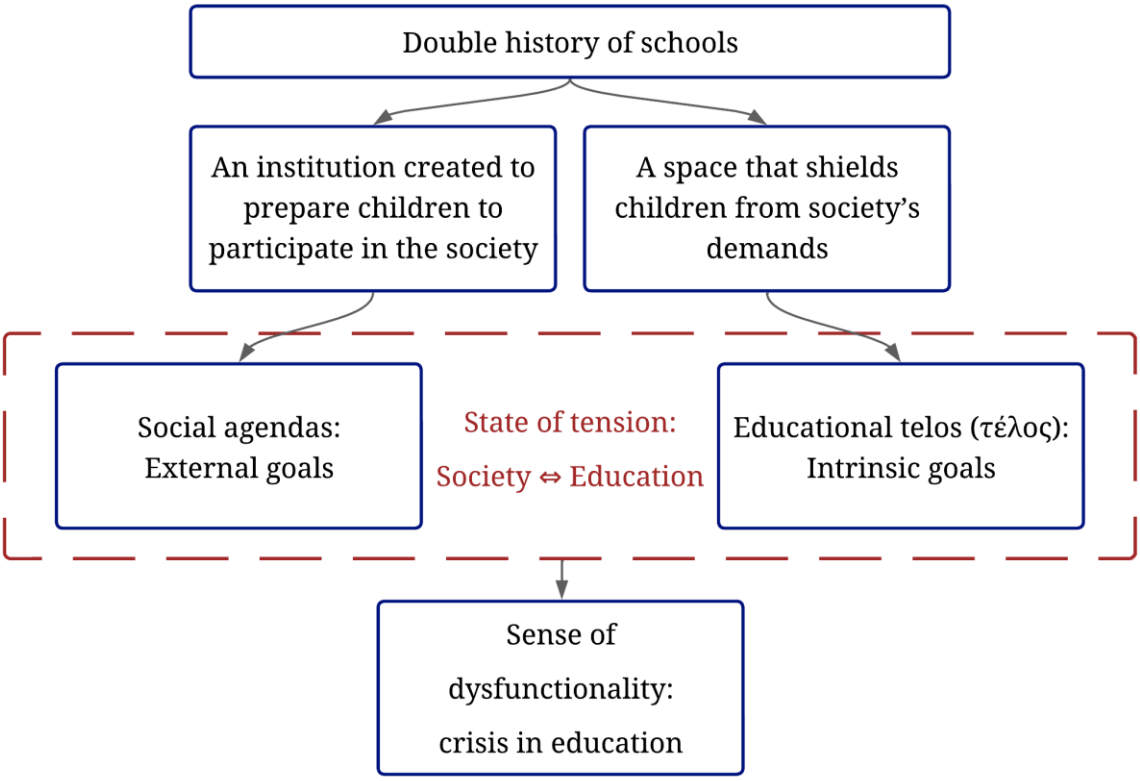
For Biesta, even though those agendas set by society may have good intentions, it is somewhat problematic because others are setting agendas for education and, a posteriori, likewise accuse education of "dysfunctionality". Because it is not delivering their agenda, a sense of crisis in education is established. In the meantime, an intrinsic agenda of education seems to dissipate (not meaning that education indeed have no problems while attempting to achieve its intrinsic goals).

Among the discourses present in education, the idea of crisis in education is translated into a relentless claim for innovation and the urge to adapt to an ever-changing world (Biesta, 2021a). In this vein, (Biesta, 2021b) states that those reports capture a switch of agendas and a movement around the relationship between education and society, wherein education has increasingly been addressed in a functional or subservient role regarding society.

Some demands from society towards education might be pretty legitimate. In this sense, international organisations have published several reports on the necessity of environmental protection (IPCC, 2022; WWF, 2022) and accordingly, education has been summoned to participate in this global challenge that sustainability represents (UNESCO, 1997; United Nations, 2018): being sustainability conceived as a complex and entangled concept comprising a triad of social, environmental, and economic aspects (Brundtland, 1987).

Differently, education may be involved with elements that are not immediately related to utility, such as playfulness. A concept complex to be defined but evidently perceived in some activities, so we wish them not to have an end (Zosh et al., 2018). Figure 1 elucidates the ideas expressed through the double history of schools in the interplay between external and intrinsic goals culminating in the perception of crisis in education.

Figure 1
Double history of schools: a tension between external and intrinsic goals



As Biesta states, education is a teleological practice (Biesta, 2015c). In other words, education stands for intrinsic goals, which are, according to him, multidimensional and comprise qualification, socialisation and subjectification. He says qualification is about qualifying people to do certain things: transmitting and acquiring appropriate knowledge, skills and dispositions. The socialisation domain relates to social structures, and it denotes initiating newcomers into ways of being and doing in communities, such as cultural, professional, political and religious traditions. Biesta defends that the third purpose of schooling is subjectification, which means calling students to exist as subjects with their own ends rather than mere objects of others' ends (Biesta, 2020).

3. METHODS

As stated previously, this doctoral thesis has an article-based format—its core text compiles published, accepted, and submitted articles (Gustavii, 2012). As research method details are provided within each article, we discuss the thesis' overall research method in this chapter. Additionally, we highlight some of the individual articles' research method features to understand how they are methodologically complementary.

The thesis approaches a mixed method since the articles vary amongst qualitative and mixed research methods. In this regard, the qualitative and quantitative parts complement a nuanced and more profound comprehension of the subject (Mcmillan & Schumacher, 2005).

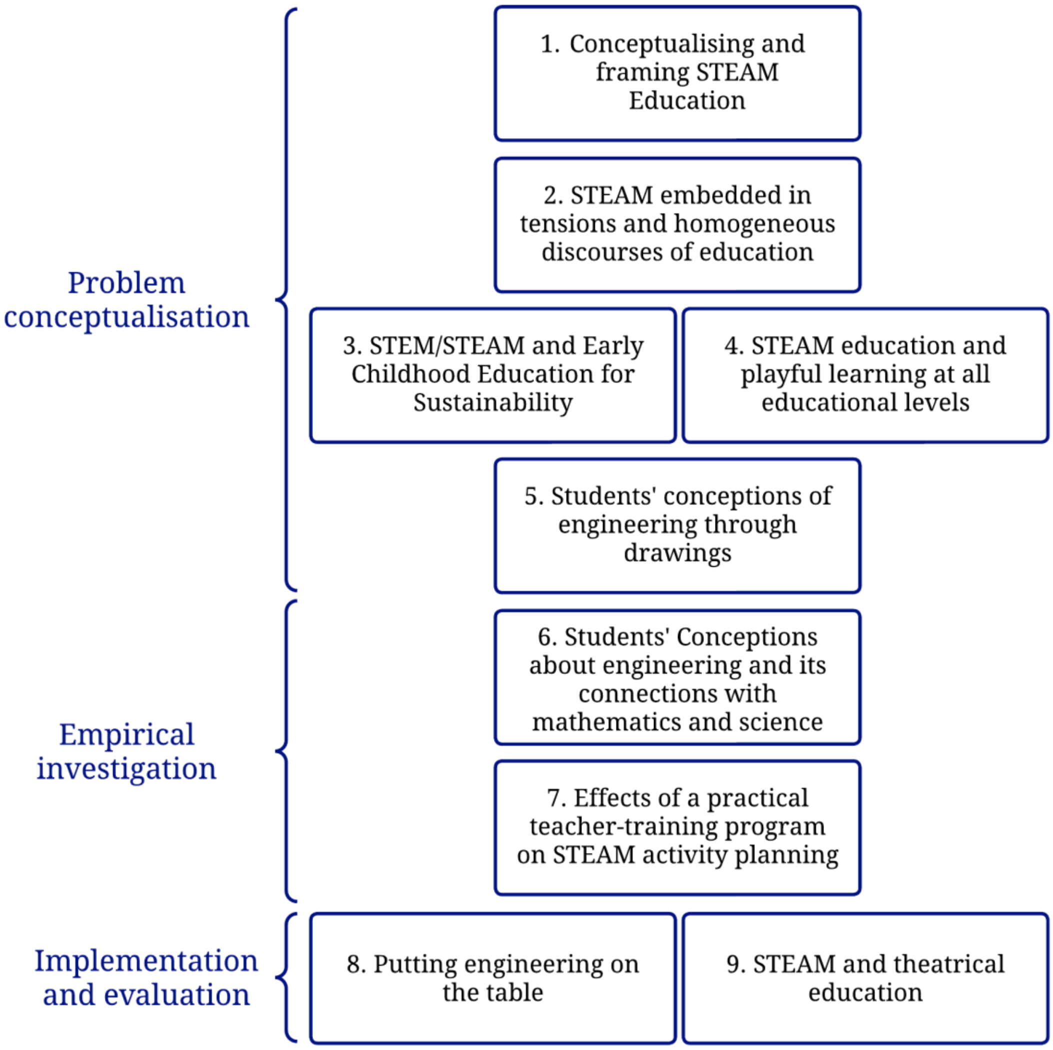
Still referring to the broad methodological framework for the thesis, we draw on the knowledge development process proposed for educational research by Mcmillan and Schumacher (2005). Those authors suggest that knowledge development in education encompasses phases such as problem definition, empirical studies, and implementation and evaluation.

The problem definition phase comprises five articles. They are narrative and systematic reviews intending to elucidate STEAM and envision it as a specific educational approach circumscribed in the breadth of education. Furthermore, in this same phase, we explore how STEAM intertwines with sustainability—as an extrinsic goal—and with playful learning—as a non-immediate social worthwhile goal.

Additionally, we highlight that STEAM implies considering engineering at precollege levels, a discipline traditionally absent from the curriculum at this age (Moore et al., 2014). Accordingly, we review students' conceptions of engineering accessed through their drawings. Next, the phase empirical investigation consists of one quasi-experimental study exploring Spanish students' conceptions of engineering and one case study examining the effects of a practical teacher-training programme on planning STEAM ability. In Figure 2, we present the articles under those three phases.

Figure 2

Articles distribution regarding the knowledge development phases in educational research



Finally, we enrolled in the implementation and evaluation phase. We addressed education's extrinsic and intrinsic goals by implementing two engineering teaching activities. One consists of a case study wherein we describe a STEAM activity of reverse engineering intertwined with sustainability. The other study comprises a Thick description of a playful drama about mechanical engineering. Table 2 lists the articles' research approach, method, data collection instrument, sample and educational level.

Table 2
Summary of articles methods

Item	Approach	Method	Data collection instrument	Sample	Educational level
Article 1	Qualitative	Narrative review	PRISMA protocols*	-	All
Article 2	Qualitative	Concept analysis	-	-	All
Article 3	Qualitative	Systematic review	PRISMA protocols	12 articles	Early childhood education
Article 4	Qualitative	Narrative review	PRISMA protocols*	-	All
Article 5	Qualitative	Systematic review	PRISMA protocols	10 articles	All
Article 6	Mixed	Quasi-experimental	Draw an Engineer Test	18 students	Elementary education
Article 7	Mixed	Case study	Questionnaire and productions	14 teachers	Professional education
Article 8	Qualitative	Case study	Field observation and productions	18 students	Elementary education
Article 9	Qualitative	Thick Description	Semi-structured interview	7 students	Higher education

Note: Narrative reviews do not follow PRISMA protocols but borrow some systematisation strategies.

The methods applied throughout the articles are systematic reviews, narrative reviews, concept analysis, quasi-experimental, case study, and thick description. Subsequently, we briefly explain each one of them.

First, we clarify the literature reviews methods. Reviews are secondary research that comprehensively gathers and combines information from a topic. Accordingly, they help make sense of the increasing volume of original publications (Ferrari, 2015). Reviews can be systematic or unsystematic—also called narrative reviews, with each type presenting advantages and limitations.

Systematic reviews follow strict protocols—such as those from Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA)—that enhance research reproducibility and reduce potential bias (Moher et al., 2015). Systematic reviews might be considered high-quality research due to their rigorous systematisation. However, systematisation requires focused scopes to make the research process well-informed, sometimes diverting from the researchers' intentions. On other occasions, systematisation is infeasible due to restrictions such as the type or low volume of available documents.

In Articles 3 and 5, we developed systematic reviews to explore precise scopes of the literature. In article 3, we reviewed the intersection between STEM/STEAM and Early Childhood Education for Sustainability. In Article 5, we reviewed studies about conceptions of engineers and engineering accessed through students' drawings. For those articles, we followed the PRISMA protocols (Moher et al., 2015). Accordingly, we structured the research into four phases: (1) search elements and Boolean logic: identification of the central terms of the research goal and synonyms; (2) eligibility criteria: setting document characteristics such as peer-reviewing, language, and publication period; (3) information sources: establishment of index bases, mainly Web of Science and Scopus; and (4) data collection and analysis: filtering using platform filters, then readings of abstract and complete documents. The analyses varied according to the articles' specific research goals.

Narrative reviews are criticised for lower reproducibility and higher potential bias. However, narrative reviews have methodological flexibility that permits addressing more extensive scopes than systematic ones (Byrne, 2016). Additionally, some systematisation can be borrowed to increase methodological clarity, such as by establishing the source of information and inclusion criteria (Ferrari, 2015). This type of research includes data synthesis and critical appraisal (Byrne, 2016) that fosters debate and provides epistemological clarifications. Consequently, it is appropriate to address subjects with divergent discourses and theoretical orientations (Green et al., 2006).

We enrolled in narrative reviews in Articles 1 and 4. Regarding Article 1, for example, we developed a narrative review because instead of focusing on specific topics circumscribed in STEAM education, we intended to make a general reflection on STEAM addressing conceptual confusion and pursuing the distinctiveness of this educational approach. Differently, in Article 4, we intended to explore the relationship between STEAM education and playful learning, which resulted in a restrictive search. Due to the lack of a document explicitly mentioning terms associated with STEAM and playful learning, we explored playful learning indirectly. We search for STEAM practices developed through the principal teaching methodologies framed in the playful learning approach: free play, guided play, game, and gamification.

In both articles, conscious that narrative reviews may limit research reproducibility and carry a higher potential for bias (FERRARI, 2015; BYRNE, 2016), we borrowed some systematisation, such as establishing the source of information and inclusion criteria to increase clarity (FERRARI, 2015). Additionally, we mitigated the risk of bias by incorporating contrary research lines regardless of personal ideological preferences.

Article 2 was enrolled as a concept analysis method willing to pursue conceptual comprehension of STEAM as a specific approach embedded in the breadth of education. We intended to explore tensions and homogeneous discourses around STEAM through Biesta's educational theory. As Mcmillan and Schumacher (2005) explain, the concept analysis method involves examining educational concepts to understand their various interpretations and suitable applications. Accordingly, concept analysis is frequently used to address educational programs, practices, institutions, individuals, and movements within historical, economic, political, and social spheres.

Article 6 comprised a quasi-experimental study examining elementary education Spanish students' conceptions of engineers and engineering. In this respect, we highlight that the results from the review presented in Article 5 helped to establish the data collection instrument Draw an Engineer Test (DAET)(Thomas et al., 2016), the hypothesis, and variables regarding Spanish students' conceptions of engineering: 1) activity, 2) place of work, 3) way of working, 4) application of interdisciplinary knowledge (mathematics and science), and 5) gender. Regarding the research method, Mcmillan and Schumacher (2005) explain that quasi-experimental research is commonly applied in education due to difficulties and sometimes impossibilities of randomising the samples. Those authors remark that quasi-experimental are close to experimental research, but there is no random assignment of subjects and not necessarily the intention of generalisation. In this Article 6, for example, since students' conceptions of engineers and engineering are unexplored in Spain, we selected an intentional sample aiming at a first approximation of the topic without the intention of generalising the result to the population of elementary education students from this country.

Articles 7 and 8 denote research through case study methods. Mcmillan and Schumacher (2005) explain that a case study can examine a programme, an event, an activity or a group of individuals defined in time and place. This research method provides a detailed case comprehension by using multiple data sources. Article 7, for example, reports a teacher training programme designed upon the considerations of the distinctiveness of STEAM resulting from conceptual exploration enrolled in the other documents. Accordingly, we should analyse this formation's effects on teachers planning STEAM ability. Therefore, we applied a variety of data collection instruments, such as closed and open-ended questionnaires and teachers' productions.

Article 8 likewise follows a case study research method. We presented a case study of the implementation of STEAM activity of reverse engineering as a didactic strategy for interdisciplinary teaching of engineering and mathematics in elementary education. We collected and analysed data from field observation and students' productions. Accordingly, we focused on observing students' strategies to reverse engineering a table and argumentations about selecting materials from a catalogue with restrictions on dimensions, price and sustainability concerns.

Eventually, Article 9 similarly reports an implementation of a STEAM activity. We aimed to describe a drama activity where mechanical engineering students conceived and performed a play about their course. Subsequently, we enrolled in Thick description as a suitable method of understanding people and peoples' self-understanding within a specific context(Tholen, 2018). A thick description adds subjective explanations and meanings provided by the individuals involved (Tholen, 2018). This method was addressed because we were interested in envisioning the educational purposes of qualification, socialisation, and subjectification. Therefore, we interviewed the students so that the description could reflect their voices and provide evidence of those educational purposes, especially subjectification.

4. RESULTS

This chapter compiles the articles published, accepted, or submitted to publication as the thesis results. In one first part, we present the subtopic “Thesis at a glance”, summarising the compiled articles and highlighting their individual primary contributions.

Then, the articles are integrally presented in the second part and accompanied by an acceptance or submission proof or the co-authors’ authorisation when applicable. It is important to note that the articles may vary in format due to adherence to different editorial guidelines.

4.1. Thesis at a glance

Table 3 presents the articles' questions, problems or literature gaps, research goals, and main results.

Table 3

Overview of the compiled articles

Document	Research question	Problem or literature gap	Research goal	Main result
Article 1	What is (and what is not) STEAM?	There is a need for reflection on the distinctiveness of STEAM. Conceptual confusion diverts it to particular activities or contexts.	Elucidate STEAM education's history, epistemology, and divergences. Pursue the essential aspects of its definition and present a framework.	We articulated the distinctiveness of STEAM compared to STEM, as a teaching methodology or a mere synonym for interdisciplinarity. Furthermore, we addressed the appropriateness of interdisciplinarity instead of transdisciplinarity. Finally, we defined and proposed a framework for STEAM in a table format stressing two necessary and sufficient conditions—interdisciplinarity and the five acronym areas.
Article 2	How is STEAM embedded in education?	It lacks comprehension of STEAM as a specific approach embedded in the breadth of education.	Explore tensions and homogeneous discourses around STEAM through Biesta's educational theory.	STEAM is an educational approach crossed through discourses that permeate education, for example, learnification and the tension between extrinsic and intrinsic goals. We proposed the movement from transdisciplinarity to interdisciplinarity—wherein teaching over the experience is fundamental to strengthening learning on the disciplines and their intersections.

Document	Research question	Problem or literature gap	Research goal	Main result
Article 3	How does STEAM intertwine with sustainability?	Early years are foundational for sustainable literacy and behaviour development. However, reflection on the intrinsic educational goals of sustainability is missing, and no previous review has specifically addressed the intersection between STEM/STEAM and Early Childhood Education for Sustainability.	Explore the intersection between STEM/STEAM and Early Childhood Education for Sustainability.	Researchers commonly report experiential learning happening in settings related to sustainability, especially in the environmental sphere. Notwithstanding, learning about sustainability and calling to act for sustainability are absent. We verified that opportunities are lost to explore social and economic spheres and to explicitly teach STEM/STEAM knowledge areas and their intersections contextualised in sustainability.
Article 4	How does STEAM intertwine with playful learning?	Although playful methodologies are applied in STEAM, there is still little depth in the articulation between STEAM education and playful learning, especially concerning older students.	Explore the relationship between STEAM education and playful learning.	A restrictive understanding of play as necessarily absent extrinsic goals may hinder the intertwining of the STEAM and Playful approaches. However, playful methodologies applied in STEAM evidence that this network is cognitively robust and feasible at all educational levels. Playful activities involve a context with a problem or a challenge where different knowledge areas can be mobilised.
Article 5	What do students conceive of engineering?	Despite increasing interest in precollege engineering—such as in STEAM—no previous study has reviewed conceptions of engineering accessed through students' drawings. Problematically, poorly designed activities may worsen students' stereotypical ideas of engineering.	Review conceptions of engineers and engineering accessed through students' drawings.	Activity, work setting, place of work, and gender are usual categories to Draw an Engineer Test's (DAET) analysis. Overall, the studies show students conceive engineers as males who enrol in manual activities, individually and outdoors. It prevails a non-intellectual conception of engineering that hinders envisioning connections to STEAM disciples such as science and mathematics.
Article 6	What do Spanish students conceive of engineering?	Spain nurtures precollege engineering while highlighting STEM competencies in the elementary education curriculum. Nonetheless, students' conceptions of engineers and engineering are unexplored in this country.	Explore Spanish students' conceptions of engineers and engineering in primary education.	Similarly to other countries, Spanish students from an elementary education class present stereotypical notions of engineering as professionals dealing with manual activities, individually and outdoors. They conceive a simplistic use of mathematics and do not visualise the use of science in engineering.

Document	Research question	Problem or literature gap	Research goal	Main result
Article 7	What do teachers think about, and how do they plan STEAM?	Teacher training is a new thread in STEAM research. Despite the reported struggles in planning STEAM activities, few teacher training programmes have been centred on this task.	Analyse the effects of a practical teacher-training programme on planning STEAM ability.	Teachers asserted attitudes towards STEAM. Although they considered merging knowledge areas challenging, especially engineering and technology, the training helped them surpass it. All plans had at least two disciplines, and half had all five STEAM areas. Around 70% of the teachers used a teaching method which was new to them. Finally, there was a significant augment in teachers' self-efficacy in planning STEAM activities.
Article 8	How might STEAM address sustainability and reverse engineering?	Students struggle to carry out engineering design without developing design competency before. Although underexplored, reverse engineering (beginning from concrete objects towards design abstraction) could be an appropriate approach to precollege engineering.	Explore reverse engineering as a didactic strategy for interdisciplinarity between engineering and mathematics.	We presented a STEAM activity in elementary education on reverse engineering. The students explored a table (object) identifying its components, function, and union elements. Mathematical learning was evidenced, such as geometric notions (square units and perimeter), measurement and operations. They demonstrated awareness between operations and their physical meanings. In addition, design strategies were developed while selecting materials in a catalogue with restrictions on dimensions, price and sustainability concerns.
Article 9	How might STEAM address playful drama and mechanical engineering?	Engineering students usually do not undergo deep reflections on their course, and they are likely to disregard social issues following a disengagement culture. In parallel, playful learning is not frequently addressed at higher educational levels, particularly drama activities concerning engineering.	Describe a drama activity of conceiving and performing a play about mechanical engineering.	We observed that drama permitted learning about engineering and theatre. Moreover, it was a space to contrast the ideal and the real engineering toward society and to call students to play the role of subjects responsible for their personal, professional and political lives.

ARTICLE 1

Conceptualising and framing STEAM education

What is (and what is not) this educational approach?

Rodrigues-Silva, J., & Alsina, Á. (2023). Conceptualising and framing STEAM education: What is (and what is not) this educational approach? *Texto Livre* (In press).

Conceptualising and framing STEAM education: What is (and what is not) this educational approach?

Conceitualização e modelo da educação STEAM: O que é (e o que não é) esta abordagem educacional?

Jefferson Rodrigues-Silva

Ángel Alsina

ABSTRACT: STEAM is a recent educational approach intending the interdisciplinary teaching of science, technology, engineering, arts/humanities, and mathematics. The literature reports conceptual confusion that frequently diverts STEAM practice and research to issues concerning particular activities or contexts. Therefore, we carried out a narrative review of articles indexed in the Web of Science (WoS) to elucidate STEAM education's history, epistemology, and divergences. As a strategy, we first focused on documents that could offer a panoramic view of the object of study—literature reviews and articles about STEAM frameworks. Through them, we identified essential discussion points and further expanded the review. As a result, we articulated rationalities about why STEAM is not a mere evolution of STEM, a teaching methodology, or just a synonym for interdisciplinarity. Furthermore, we discussed the appropriateness of interdisciplinarity in STEAM—since it is strongly supported by the disciplines and their intersections—instead of pursuing transdisciplinarity, meaning knowledge remains undefined in a holistic whole. We differentiated STEAM disciplines (list of the five knowledge areas), STEAM activities (interdisciplinary teaching unity of at least two STEAM disciplines), and STEAM education (educational approach of interdisciplinarity between all five disciplines). Finally, we defined and proposed a framework for STEAM in a table format that stresses two necessary and sufficient conditions—interdisciplinarity and the five acronym areas. The framework permits envisioning the plurality of teaching methodologies and educational objectives consistent with STEAM.
KEYWORDS: Educational models. Integrated curriculum. Interdisciplinary approach.

RESUMO: STEAM é uma abordagem educacional recente que visa o ensino interdisciplinar de ciência, tecnologia, engenharia, artes/humanidades e matemática. A literatura relata confusão conceitual que frequentemente desvia a prática e a pesquisa de STEAM para questões relacionadas a atividades ou contextos específicos. Portanto, realizamos uma revisão narrativa de artigos indexados em Web of Science (WoS) para elucidar a história, epistemologia e divergências da educação STEAM. Como estratégia, primeiro nos centramos em documentos que pudessem oferecer uma visão panorâmica do objeto de estudo - revisões da literatura e artigos que discutem modelos teóricos de STEAM. Identificamos junções essenciais de discussão e expandimos a revisão. Articulamos racionalidades sobre por que STEAM não é uma evolução do STEM, uma metodologia de ensino ou um sinônimo de interdisciplinaridade. Além disso, discutimos a adequação da interdisciplinaridade em STEAM, que é fortemente apoiada pelas disciplinas e suas interseções; em vez da transdisciplinaridade, em que o conhecimento permanece difuso dentro de um todo holístico. Diferenciamos os conceitos disciplinas STEAM (lista das cinco áreas de conhecimento), atividades STEAM (unidade de ensino interdisciplinar de pelo menos duas disciplinas STEAM) e a educação STEAM (abordagem educacional de interdisciplinaridade entre todas as cinco disciplinas). Finalmente, definimos e propusemos um modelo para STEAM em formato de mesa que

destaca duas condições necessárias e suficientes - interdisciplinaridade e as cinco áreas do acrônimo. O modelo permite visualizar a pluralidade de metodologias de ensino e objetivos educacionais consistentes com STEAM.
PALAVRAS-CHAVE: Modelos educacionais. Currículo integrado. Abordagem interdisciplinar.

1 Introduction

Interdisciplinarity pedagogies have been advocated through the rationality that siloed knowledge cannot address complex and global issues (PERIGNAT; KATZ-BUONINCONTRO, 2019). Following this, the United States of America (USA) forged the acronym STEM in the 90s, referring to the integration of science, technology, engineering, and mathematics. Alternatively, STEAM emerged, considering science, technology, engineering, arts/humanities, and mathematics (CHESKY; WOLFMEYER, 2015).

Since their formalisation, STEM and STEAM have progressed in research and practice as interdisciplinary approaches between the areas circumscribed in each acronym. They incorporate current critical knowledge, such as technology and engineering, traditionally absent from pre-college levels. Bibliometric studies confirm they have advanced as research lines in education (MARÍN-MARÍN et al., 2021). Several countries, e.g. the USA, Korea, and Spain, have embraced them in their curriculums (KOFAC, 2013; MEFP, 2022; NGSS, 2013). The literature reports experiences in STEM or STEAM that mention successful outcomes in integrating knowledge areas and developing sustainable concerns such as environmental protection, food literacy, and gender equity (COSTA-LIZAMA et al., 2022; SILVA-HORMAZÁBAL et al., 2022; STEPHENSON; FLEER; FRAGKIADAKI, 2022).

Despite the enthusiasm, STEM and STEAM face criticism and epistemological divergences. The bifurcation of the acronyms itself signals those divergencies. STEM and STEAM represent contrary lines of narrowing the curriculum into technical areas or broadening it with arts and humanities. In the first direction, researchers defend that the expansion of STEM weakens the coherence of technical areas (CLEMENTS; SARAMA, 2021). Contrarily, other researchers intend to broaden the curriculum through the non-exclusion of arts and humanities. The latter propose STEAM precisely to prevent the concentration or privilege of technical areas (PERIGNAT; KATZ-BUONINCONTRO, 2019).

Specifically addressing STEAM, this educational approach is embedded in contemporary educational research and practice tendencies. For instance, STEAM is predominantly oriented toward the socio-constructivist paradigm and claims configurations such as active, collaborative, authentic, and meaningful learning (SCHLESINGER et al., 2020). Practitioners frequently adopt active teaching methodologies such as Project-Based Learning (PjBL), Problem-Based Learning (PBL), and games (AGUILERA; ORTIZ-REVILLA, 2021).

Literature reviews have focused on specific characteristics and contexts of STEAM, such as intertwined with playful learning or in Early Childhood Education for Sustainability (ECEfS) (RODRIGUES-SILVA; ALSINA, 2022b, 2023a). Meanwhile, there is a conceptual misunderstanding of what is essential in STEAM. In this vein, some studies propose frameworks for STEAM, but they incorporate features that restrict it to particularities of some educational settings, teaching methodologies, and contexts. There is a literature gap in a broader reflection on the distinctiveness of STEAM: what differentiates STEAM from a mere synonym of interdisciplinarity; what differentiates mentioning STEAM disciplines from single STEAM activities or the whole STEAM education.

Considering all that, we inquire—what is (and what is not) STEAM education. At the same time, we address the literature gap for comprehensive reviews and non-restrictive frameworks of STEAM. Accordingly, we aim to elucidate STEAM education's history, epistemology, and divergences. Following, we pursue defining it and present a framework focusing on STEAM's essential aspects.

2 Methodology

Reviews can be systematic or unsystematic—also called narrative reviews. Each type of review presents advantages and limitations. Complementarly, they help make sense of the increasing volume of original publications (FERRARI, 2015).

Systematic reviews follow strict protocols that enhance research reproducibility and reduce potential bias. On the other hand, systematisation requires more focused scopes to make the research process well-informed. Differently, narrative reviews have methodological flexibility that permits addressing more extensive scopes (BYRNE, 2016). Narrative reviews include data synthesis and critical appraisal (BYRNE, 2016). This type of qualitative research fosters debate and provides epistemological clarifications. It is proper to address subjects with divergent discourses and theoretical orientations (GREEN; JOHNSON; ADAMS, 2006).

Accordingly, we developed a narrative review because the research goal embraces the breadth of STEAM education instead of focusing on specific topics circumscribed in STEAM education. Conscious that narrative reviews may limit research reproducibility and carry a higher potential for bias (FERRARI, 2015; BYRNE, 2016), the authors borrowed some systematisation, such as establishing the source of information and inclusion criteria to increase clarity (FERRARI, 2015). Additionally, they mitigated the risk of bias by incorporating contrary research lines regardless of personal ideological preferences.

We established the Web of Science (WoS) as the primary data source because this index has a relevant impact on scientific production, particularly in education. Additionally, we set articles that underwent peer review because this process suggests some research quality (ARDOIN; BOWERS, 2020).

First, we used WoS filters to scan articles indexed in the category of educational research with the terms STEM or STEAM in its topic–title, abstract, and keywords. This first approach was intended to display the quantitative reality of research on those educational approaches.

Subsequently, we concentrated the search by scanning STEAM in the article's topics. Accordingly, we applied the eligibility criteria clarified in Table 1—peer-reviewed articles published in English, Spanish or Portuguese from 2007 to 2022.

Tabela 1. Eligibility criteria

Inclusion criteria		Reasons
Assessment	peer review	Peer-reviewed documents have gone through an evaluation process that suggests research quality (ARDOIN; BOWERS, 2020)
Web of Science categories	Educational research, science subjects or special education	Concentrate on the educational areas and prevent unrelated documents wherein STEAM means vapour
Document type	Literature reviews and STEAM frameworks	STEAM frameworks and literature reviews give a panoramic view of the object of study (MOHER *et al.*, 2015)
Language	English, Spanish or Portuguese	These languages have high coverage in Western educational research
Period	From 2007 to 2022	Time frame corresponding to the STEAM acronym creation (PERIGNAT; KATZ-BUONINCONTRO, 2019) until the present day

Source: the authors.

At this point, we focused on documents that could offer a panoramic view of the object of study—literature reviews and articles discussing STEAM frameworks. For example, Ortiz-Revilla, Sanz-Camarero, and Greca (2021) reviewed nine studies concerning the frameworks of STEAM. Those articles presented several divergences in STEAM conceptualisation. After in-depth reading and multiple comparisons of those texts, we identified essential points of discussion—predominantly epistemological interpretation of the STEAM approach.

Following, we expanded the set of articles considering the identified joints on STEAM education's history, epistemology, and divergences. Additionally, we conducted a snowball process, which involved analysing the references of the already selected documents to find related works (GREEN; JOHNSON; ADAMS, 2006). At this point, we remark that a narrative review does not intend to confine the study to a list of documents. It targets condensing the information and addressing points of divergence (GREEN; JOHNSON; ADAMS, 2006).

3 Results

We present the results according to points identified as essential for the conceptualisation and definition of STEAM: i) STEAM education history, ii) what STEAM is not, iii) STEAM definition, and iv) the STEAM education framework.

3.1 STEAM education history

Bibliometric investigations from the begging of modern science in the eighteenth century to the present day indicate an exponential growth rate of scientific knowledge with a doubling time of 17.3 years (BORNMANN; HAUNSCHILD; MUTZ, 2021). Epistemologically, knowledge generation has tended towards an episteme of analysis—a specialisation angle (FLORENTINO; RODRIGUES, 2015). As deliberating over everything became humanly impossible, knowledge had to be divided into areas and individuals were expected to have solid mastery over specific subjects and tasks. Successively, epistemological complexity was accompanied by a so-called hyper-specialisation

(MALONE; LAUBACHER; JOHNS, 2011).

In parallel, knowledge accumulation made epistemological complexity apparent (FLORENTINO; RODRIGUES, 2015). On the one hand, specialisation seemed powerful regarding particular topics. On the other hand, knowledge fragmentation showed itself ineffective in addressing complex issues (DANERMARK, 2019). In between this tension, interdisciplinary research and education approaches emerge following the rationality that knowledge areas should be integrated because isolated disciplines can no longer grasp complex contemporary problems (FLORENTINO; RODRIGUES, 2015; UNESCO, 1997).

Beyond the quantity of knowledge, there is a growing interest in scientific and technical areas. Prudently, we suggest a temporal and geographically unclear origin of this interest. However, some historical events, such as the industrial revolutions from the eighth century (XU; DAVID; KIM, 2018), indicate the prominence of scientific and technological knowledge. Following this, a need for interdisciplinary educational approaches is accompanied by a curricular renovation incorporating knowledge areas such as technology and engineering. Figure 1 presents events culminating in STEM and, subsequently, in STEAM education.

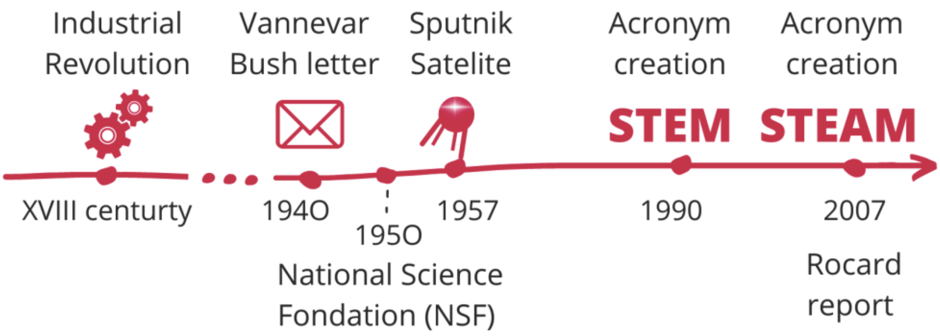


Figure 1. STEAM education timeline
Source: the authors.

Early as 1940, for example, the engineer Vannevar Bush addressed official letters to the USA president Eisenhower emphasising the urgency of creating educational structures to prepare future scientists foreseeing the prosperity of that country (CHESKY; WOLFMEYER, 2015)

During the cold war (1947 – 1991), the United States of America (USA) and the Union of Soviet Socialist Republics (USSR) experienced ferocious competition for technological supremacy (CHESKY; WOLFMEYER, 2015). Those countries embraced policies aiming at technical, economic, and military development that touched various spheres of society, including education. Educational policies focused efforts—and principally investments—on developing specific scientific and technological careers considered national interest (CATTERALL, 2017).

An essential point was the National Science Foundation (NSF) creation in 1950—a governmental agency aimed to promote education and research in science and engineering (NSF, 1950). Seven years later, the Russian Sputnik-1 satellite was launched into orbit around the Earth. This revolutionary event triggered many USA reactions

(PERIGNAT; KATZ-BUONINCONTRO, 2019). Among some of these responses, NSF formalised the acronym STEM in 1990 to refer—and principally justify—what became known as an investment “pipeline” in science, technology, engineering and mathematics (REYNOLDS *et al.*, 2009; STEPHENSON; FLEER; FRAGKIADAKI, 2022).

Indeed, the STEM movement was initially justified by economic and military competitiveness (CHESKY; WOLFMEYER, 2015). Nevertheless, this movement later progressed to STEM education—an educational approach centred on interdisciplinarity between the areas constituting the acronym (KELLEY; KNOWLES, 2016). In this transition, STEM incorporated educational trends and discourses such as active, collaborative, authentic, meaningful, and playful learning (MICHAEL, 2006; ZOSH *et al.*, 2018)

STEM implied educational investment policies narrowed to technical areas (REYNOLDS *et al.*, 2009; STEPHENSON; FLEER; FRAGKIADAKI, 2022). In opposition, representatives revindicate against the devaluation in American schools of the areas left out of the acronym. Accordingly, the new acronym STEAM was formalised at the Americans for the Arts-National Policy Roundtable, including A for the arts (PERIGNAT; KATZ-BUONINCONTRO, 2019).

Following this, researchers argued that STEAM could be more comprehensive than STEM by encompassing arts and humanities (GUYOTTE, 2020). The same, UNESCO established STEAM as an appropriate approach to achieving Sustainable Development Goals (SDGs) (UNITED NATIONS, 2018) while conceiving sustainability as a broader concept that includes social, environmental and economic aspects (BRUNDTLAND, 1987).

STEM and STEAM have been adopted in many countries and continents. The European Commission, for example, published a report proposing a new pedagogy for the future of Europe with an emphasis on science education (ROCARD *et al.*, 2007). Parallelly, those approaches have grown as educational research lines (MARÍN-MARÍN *et al.*, 2021). Figure 2 shows the number of articles indexed on the Web of Science (woS) in the category of educational research with the terms STEM or STEAM in its topics (title, abstract or keywords). We note that research in STEAM is still much less expressive than in STEM. Considering the number of publications in the graph, STEAM represents only 6%.

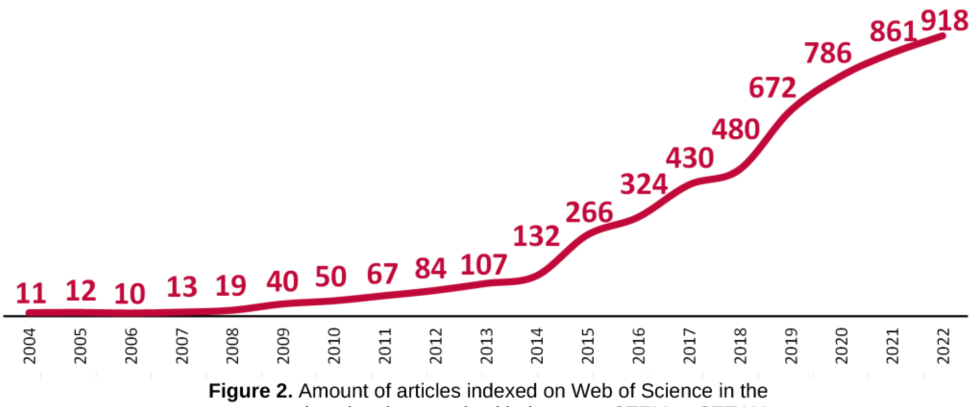


Figure 2. Amount of articles indexed on Web of Science in the category educational research with the terms STEM or STEAM.

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The authors of this review clarify their inclinations towards STEAM education vis-à-vis its inclusiveness of arts and humanities. STEAM is more comprehensive in addressing complex issues such as sustainability (RODRIGUES-SILVA; ALSINA, 2023b; UNITED NATIONS, 2018). Rather than merely fulfilling utilitarian goals and agendas extrinsic from education, we believe STEAM has significant potential to meet subjects' purposes and those intrinsic to education (BIESTA, 2022; RODRIGUES-SILVA; ALSINA, 2023b).

3.2 What STEAM is not

We do not intend to define STEAM by its negative, but we are confident that reflecting on what STEAM education is not may contribute to elucidating it. In this direction, we explore the underpinning rationale which supports that STEAM is not an evolution of STEM, a teaching methodology, a synonym of interdisciplinarity, or an attempt to erase the disciplines (based on transdisciplinarity).

STEAM is not an evolution of STEM: STEM and STEAM education are inexorably interconnected because one emerged as a response to the other (PERIGNAT; KATZ-BUONINCONTRO, 2019). Additionally, both approaches share interdisciplinary teaching at their core and imply the insertion of engineering and technology pre-college curricula (MOORE *et al.*, 2014).

However, if STEAM contains all four areas of the previous acronym, why do some people advocate for STEM over STEAM? There should be differences that justify this positioning. Liao (2019) explains that some STEM practitioners reject the extension of the acronym, fearing to divert attention (privilege) from technical areas. In this vein, Clements and Sarama (2021) warn that broadening the acronym to other knowledge areas will likely weaken the cohesion of STEM education. However, they oversee that perhaps that is precisely what STEAM defensors intended in the first place.

The conflict that motivates STEAM as a response to STEM remains central to their relationship. On the one hand, STEM represents a convergent standpoint of selecting specific areas of knowledge—meaning not including humanistic disciplines. On the other hand, STEAM proposes reinserting arts and humanities into the educational programme. This conflictual relationship allows stating that STEAM is not simply an evolution of STEM because they reflect contradictory philosophies regarding narrowing or broadening the curriculum.

STEAM is not a teaching methodology: STEAM usually endorses active, collaborative, authentic, meaningful, and playful learning (MICHAEL, 2006; ZOSH *et al.*, 2018). In parallel, several teaching methodologies are argued to support STEAM in those learning settings. Accordingly, STEAM activities have been developed by teaching methodologies such as Project-Based Learning (PjBL) (LU; LO; SYU, 2021), Problem-Based Learning (PBL), and Inquiry-Based Learning (IBL) (QUIGLEY; HERRO; JAMIL, 2017). Furthermore, reports highlight positive outcomes of STEAM intertwined with playful approaches such as Free play, Game-Based Learning, and Gamification (AURAVA; MERILÄINEN, 2022; RODRIGUES-SILVA; ALSINA, 2022a).

This plurality of strategies is restricted if STEAM is portrayed as aligned with one specific teaching methodology. Such simplification hinders the dialogue between STEAM practitioners and researchers who envisioned STEAM through different pedagogical strategies. In other moments, STEAM is misguided as a teaching methodology itself. While occupying a place of methodology, STEAM overshadows teaching methodologies that could benefit STEAM with theoretical and empirical knowledge historically constructed on them. Additionally, this misunderstanding generates discredit associated with the feeling that STEAM is just another name for concepts already consolidated in educational research.

In sum, STEAM education should not be restricted to or understood as a teaching methodology. Even though a STEAM activity might be inevitably circumscribed in a specific teaching methodology, various teaching methodologies contribute to various undertakings aiming at the interdisciplinary teaching of STEAM disciplines (we will differentiate STEAM education from STEAM activity later).

STEAM is not a synonym for interdisciplinarity: First, we clarify that disciplines represent branches of knowledge that can be distinguished from other knowledge areas according to different epistemology, theories, and methods. Disciplines or knowledge areas are comprehensible parts of knowledge that permit its organisation (FLORENTINO; RODRIGUES, 2015). Following, we query the various forms they can relate to each other. As shown in Figure 3, the word discipline is commonly accompanied by the prefixes intra, cross, multi, inter and trans. Those modifiers express concepts widely used, and frequently misunderstood, in the literature.

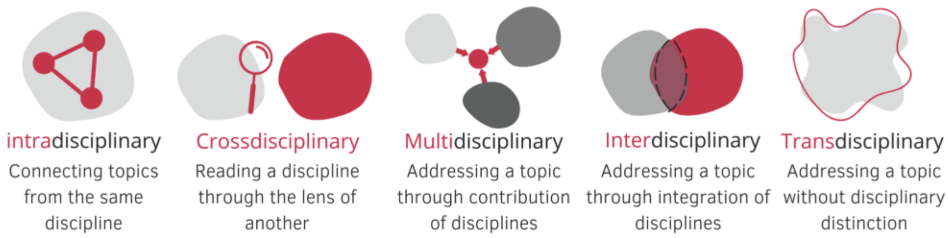

Figure 3. Disciplinary relations
Source: the authors.

Intradisciplinary addresses the connection of topics within the scope of the same discipline. Cross-disciplinary observes a topic from one discipline, taking the perspective of another. Multidisciplinary means that disciplines separately contribute to understanding a topic or problem. Interdisciplinarity concerns integrating disciplines so that there is dialogue through them and their interspaces or intersections (DANERMARK, 2019). Differently, transdisciplinary aims to synthesise knowledge so that a topic can be holistically comprehended.

Repeatedly, multi, inter and transdisciplinary are interchangeably enunciated so that their meaning differences are emptied. Politi (2019) argues that those three concepts represent progressive stages of disciplinary integration—with transdisciplinary referring to the latest stage of this process. Nonetheless, this assumption of one integration process carries incompatibilities.

In interdisciplinarity, discipline borders are momentaneously crossed to highlight their intersections. This way, disciplines can be integrated through dialogue that provides understanding within and synergistically beyond the disciplines' original scope. Consequently, interdisciplinarity place disciplines as essential substrates for integration, and they are strengthened by contact with each other (BOUFLEUER; MOURA, 2020; FLORENTINO; RODRIGUES, 2015).

Conversely, transdisciplinarity seeks to transcend the boundaries of disciplines while considering a holistic whole that would better address complex issues (GUYOTTE *et al.*, 2014). In transdisciplinarity, the focus remains on the problem without discerning individual disciplines and outlining intersections. Hence, instead of a superior stage of interdisciplinarity, transdisciplinarity represents a different, perhaps opposing concept.

Importantly, interdisciplinarity and STEAM are not synonymous because the former refers to the dialogue between disciplines (in general), and the latter consists of such dialogue considering the group of disciplines described in the acronym. Consequently, beyond interdisciplinarity, STEAM implies a curriculum modernisation considering relevant knowledge areas introducing disciplines traditionally overseen at pre-college levels—technology and engineering (MOORE *et al.*, 2014).

STEAM is not an attempt to erase the disciplines: Initially, listing disciplines in the acronym of an educational approach that aims at integration possibly seem confusing. At the same time, it can sound reasonable wondering the creation of one holistic macro discipline instead of mentioning discrete knowledge areas.

Indeed, students are likely to learn holistically from experiences in activities wherein they are unaware of which knowledge areas are being applied—as suggested in transdisciplinarity (STROBEL *et al.*, 2013). Notwithstanding, interdisciplinary education is distinctive from everyday learning precisely when offering insights from the disciplines. In this sense, interdisciplinarity fosters students' reflection on experiences to build consciousness about the disciplines, strengthen disciplinary knowledge, and explore their intersection (FLORENTINO; RODRIGUES, 2015; PEARSON, 2017). In other words, while transdisciplinarity might result in some learning from experience, interdisciplinarity further explores those experiences by explicitly addressing the disciplines involved.

Consequently, we argue that interdisciplinarity is a central aspect of STEAM. In order to be educational, STEAM requires an understanding of each discipline and its intersections (THIBAUT *et al.*, 2018). In STEAM, teachers have to teach (BIESTA, 2020)—they encourage reflection on experiences and convey knowledge students would not recognise as such from merely experiencing an activity. Hence, STEAM is not an attempt to erase the disciplines. Contrarily, this educational approach is firmly grounded in the disciplines that constitute it.

3.3 STEAM education definition

First, we evoke the five general rules of definition: exclusion of the negative, adequacy, clarity, non-circularity, and brevity (MACHLARZ, 2011). Among them, we recall the rule of exclusion of the negative states that definitions must not come from the negative. Therefore, we elucidate that the considerations on the negative of STEAM presented so far helped to understand but do not define it.

Next, we articulate two conditions for STEAM education—interdisciplinarity and the knowledge areas of science, technology, engineering, arts/humanities, and mathematics. First, we outline that recalling **STEAM disciplines means distinctively listing the acronym's knowledge areas**. Next, we highlight that, on the one hand, although interdisciplinarity is central to STEAM, it does not encompass the whole idea of STEAM regarding setting a group of disciplines as pertinent to current and future society. On the other hand, only establishing a group of STEAM disciplines does not configure STEAM education—an educational approach that aims to integrate those disciplines.

Therefore, these conditions are necessary and sufficient (if together) to define STEAM. Accordingly, **STEAM education is an educational approach that promotes interdisciplinary teaching of the STEAM disciplines in its set of practices**.

Further exploring this definition, it appreciates all the letters of the acronym in their quality of knowledge area. Researchers defend that teaching in STEAM should not hierarchise the disciplines. In other words, one area should not is reduced to an educational tool in service to teach other (MEJIAS *et al.*, 2021).

Moreover, we remark that STEAM education means teaching all areas of the acronym. In this respect, Toma and García-Carmona (2021) criticise that the literature in STEM/STEAM is too pretentious for promoting a set of areas in the acronyms if practitioners are content with the requirement to integrate at least two areas. However, these authors disregarded that education is not attained with a single session or activity. In this sense, it is worth differentiating STEAM activity from STEAM education. STEAM activity or lesson is an educational practice aligned with, but that does not necessarily fulfil all conditions of STEAM because it is a single episode of STEAM education. Thus, **STEAM activity or lesson is a practice of interdisciplinary teaching of at least two STEAM disciplines**.

STEAM activities should contemplate at least two areas to ensure interdisciplinarity. In this sense, a STEAM activity has to be planned according to the pertinence of STEAM disciplines regarding a particular topic or problem. For the same reason, it may be appropriate for one discipline to be central and the other to play complementary roles in a specific activity. At this level, interdisciplinary didactic planning should prioritise students' learning benefits rather than desperately forcing the presence of all STEAM disciplines (PEARSON, 2017; THIBAUT *et al.*, 2018) or misleadingly pursuing equilibrated development between the areas.

Especially in empirical studies, researchers explore STEAM activities—which naturally have particular settings— and tend to extrapolate the specific characterisation of those activities to STEAM education. When brevity is abandoned in the STEAM definition, it generates disagreement due to unnecessary restrictions. For example, authenticity—addressing real-world problems—might be vital in several STEAM activities (STROBEL *et al.*, 2013). Nevertheless, a definition of STEAM Education that includes authenticity would conflict with, for example, playful learning, whose activities are embedded in imagination, fantasy, and mythical contexts (RODRIGUES-SILVA; ALSINA, 2023a).

In this sense, besides brevity, the definition of STEAM education presented here complies with the rule of adequacy because it suits the defined object and nothing else. Furthermore, it is clear and non-circular because the term to be defined is not in the body of the definition. Finally, we argue that instead of changing and stretching the definition of STEAM to accommodate particular activities, we propose envisioning the breadth of STEAM education coherent from various teaching methodologies and educational purposes.

3.4 STEAM education framework

Characterising differs from defining regarding its no pretension of reaching exhaustion (MACHLARZ, 2011). Thus, STEAM is usually characterised by active, collaborative, authentic, meaningful, and playful teaching and learning (LIN; TSAI, 2021; ORTIZ-REVILLA; SANZ-CAMARERO; GRECA, 2021; QUIGLEY; HERRO; JAMIL, 2017). Undoubtedly, those configurations and teaching and learning are relevant to STEAM education since literature has pointed out them as effective strategies for education on many occasions (MICHAEL, 2006).

Briefly mentioning, researchers propose STEAM activities aiming at the development of creativity (AGUILERA; ORTIZ-REVILLA, 2021), critical thinking (BASSACHS *et al.*, 2020), engineering thinking (RODRIGUES-SILVA, SILVA-HOMAZÁBAL, ALSINA, 2023), and food literacy (SILVA-HORMAZÁBAL *et al.*, 2022). In this line, STEAM might be appropriate to address various objectives intrinsic to education, from the subject (BIESTA, 2020), and aligned with international agendas of social interest, such as Education for Sustainability (GUYOTTE, 2020; VÁSQUEZ *et al.*, 2021),

Considering all that, we propose in Figure 4 a conceptual framework of STEAM in a table format incorporating STEAM definition (exhaustive) and characterisation (non-exhaustive). From this picturisation, we remark that the table top—the part that makes the table a table—represents STEAM's two sufficient and necessary conditions. Differently, teaching methodologies and objectives are closely related to specific STEAM activities instead of defining STEAM as an educational approach. Therefore, we represent teaching and learning configurations as the table legs—although significant, missing one table leg does not disqualify it as a table. Eventually, we represent educational objectives as constructions on the table—they are supported by the whole table.

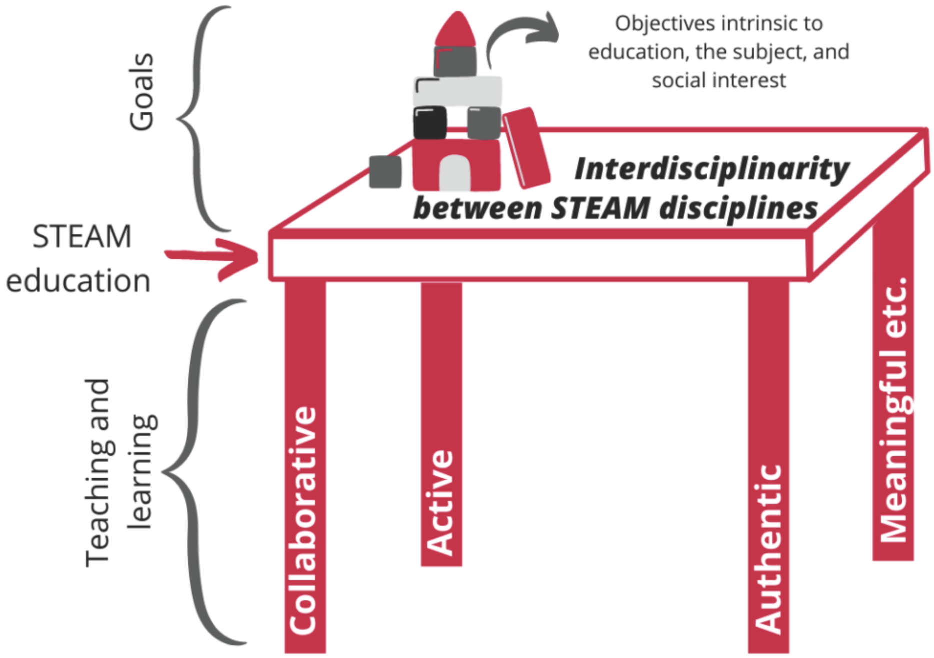

Figure 4. Conceptual framework of STEAM education
Source: the authors.

Notably, teaching and learning configurations and objectives are accompanied by an "etcetera" to reaffirm the non-intention of exhaustion in the characterisation of STEAM education.

4 Conclusions

As Marín-Marín *et al.* (2021) evidenced, STEAM is a recent research line still under construction. Accordingly, this review pointed out some STEAM definition incongruences which may be problematic to its understanding and practice (PERIGNAT; KATZ-BUONINCONTRO, 2019). Therefore, we inquired about what is (and what is not) STEAM education.

In response, this study elucidated that STEAM is not a simple evolution of STEM nor a teaching methodology. We expressed rationalities underpinning STEAM as an interdisciplinary approach—strongly supported by the disciplines and their intersections—instead of pursuing transdisciplinarity, where knowledge remains undefined in a holistic whole.

We could differentiate STEAM disciplines (list of the five knowledge areas), STEAM activities (interdisciplinary teaching unity of at least two STEAM disciplines), and STEAM education (educational approach of interdisciplinarity between all STEAM disciplines).

Finally, we proposed a STEAM conceptual framework in a table format. This framework contributes by emphasising the essential aspects of STEAM definition (table top). This characterisation mentions some teaching methodologies and educational objectives but is not restrictive, asserting the multiplicity of doings of education, paradigms and methodologies already existing in the literature.

The conclusions from this review impact STEAM practice calling attention to teaching as an addition that makes this approach distinctively education in regard to everyday learning (knowledge diffused). While stressing interdisciplinarity, we assert the importance of further exploring students' experiences by explicitly addressing the disciplines and their intersections. Concerning teacher education, on the one hand, STEAM requires teacher professional development that enhances agency on a plurality of teaching methodologies associated with STEAM to achieve educational goals. On the other hand, individual STEAM activities require proper lesson planning, including the ability to select appropriate disciplines and intentionally develop them. At the same time, STEAM education remarks the need to articulate all STEAM disciplines, including technology and engineering, that knowledge areas traditionally missing at pre-college levels.

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Acceptance proof

Gmail **Jefferson Rodrigues-Silva <jeffe.rodri@gmail.com>**

[TL] Decisão editorial

4 mensagens

Daniervelin Renata Marques Pereira <textolivreufmg@gmail.com> 20 de abril de 2023 às 13:46
Para: Jefferson Rodrigues-Silva <jeffe.rodri@gmail.com>, Ángel Alsina <angel.alsina@udg.edu>

Jefferson Rodrigues-Silva, Ángel Alsina:

Nós chegamos a uma decisão referente a sua submissão para o periódico Texto Livre: Linguagem e Tecnologia (ISSN 1983-3652), "Conceitualização e estrutura da Educação STEAM: O que é (e o que não é) esta abordagem educacional?".

Nossa decisão é de: Aceitar a Submissão.

Atenciosamente,

Daniervelin Pereira

Editora da revista Texto Livre

____

Daniervelin Renata Marques Pereira

textolivreufmg@gmail.com
Texto Livre

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Jefferson Rodrigues-Silva <jeffe.rodri@gmail.com> 3 de maio de 2023 às 11:13
Para: Daniervelin Renata Marques Pereira <textolivreufmg@gmail.com>

Prezada Dra. Daniervelin Pereira,

Estamos muito contentes em termos uma contribuição na Texto Livre.

2

ARTICLE 2

STEAM in tensions and homogeneous discourses of education

Rodrigues-Silva, J., & Alsina, Á. (In submission). STEAM in tensions and homogeneous discourses of education.

STEAM in tensions and homogeneous discourses of education

Jefferson Rodrigues-Silva, Ángel Alsina

Abstract

We sought to explore tensions and homogeneous discourses around STEAM education (interdisciplinary teaching of Science, Technology, Engineering, Arts/Humanities and Mathematics) through Biesta's educational theory. For that, we delved into Biesta's ideas about the double history of schools and the tensions between extrinsic and intrinsic goals of education. Then, we examined the *learnification* discourse and his recommendation of returning the vocabulary from learning back to teaching. Subsequently, we deepen on how those ideas are reflected in STEAM. We observed aspects, such as the instrumentalisation discourse, that are not distinctive of STEAM but comprehensive of education. Additionally, the examination highlighted the role of teaching in STEAM. Accordingly, the *learnification* discourse was translated to STEAM through a parallel movement from transdisciplinarity (meaning transcending disciplines and focusing on learning) to interdisciplinarity (meaning strengthening disciples through their integration and considering teaching).

Keywords: STEAM education. STEM education. Learnification discourse. Gert Biesta.

STEAM em tensões e discursos homogêneos da educação

Resumo

Objetivou-se explorar as tensões e os discursos homogêneos em torno da educação STEAM (ensino interdisciplinar de Ciências, Tecnologia, Engenharia, Artes/Humanidades e Matemática) por meio da teoria educacional de Biesta. Para isso, aprofundou-se nas ideias de Biesta sobre a dupla história das escolas e as tensões entre propósitos extrínsecos e intrínsecos à educação. Em seguida, examinou-se o "discurso da aprendizagem" e sua recomendação de voltar o vocabulário da aprendizagem de volta para o ensino. Posteriormente, aprofundou-se em como essas ideias se refletem em STEAM. Observaram-se aspectos, como o discurso da instrumentalização, que não são específicos de STEAM, mas sim abrangentes da educação. Além disso, a investigação enfatizou o ensino em STEAM. Nessa linha, Transladou-se o "discurso da aprendizagem" em STEAM por meio do movimento paralelo da transdisciplinaridade (concentrando-se no aprendizado holístico pela experiência) para a interdisciplinaridade (fortalecendo as disciplinas por meio de sua integração e considerando o ensino).

Palavras-chave: Educação STEAM. Educação STEM. Discurso da aprendizagem. Gert Biesta.

STEAM en tensiones y discursos homogéneos de la educación

Resumen

Se han explorado las tensiones y discursos homogéneos en torno al enfoque STEAM (Ciencia, Tecnología, Ingeniería, Artes/Humanidades y Matemáticas) a través de la teoría de la educación de Biesta. Para ello, se han profundizado en las ideas de este filósofo, como la historia dual de las escuelas, las tensiones entre los objetivos extrínsecos e intrínsecos de la educación y el discurso de la *aprendización*. Posteriormente, se ha discutido cómo estas ideas se reflejan en STEAM. Como resultado, se han aclarado aspectos que no son distintivos de STEAM, sino más bien amplios en la educación. Además, se ha identificado que el discurso de la *aprendización* se manifiesta en STEAM en forma de aprendizaje transdisciplinario. Por lo cual, se ha trasladado la recomendación de Biesta de retornar el vocabulario hacia la enseñanza a un movimiento en dirección a la interdisciplinariedad. En otras palabras, se ha abogado por fortalecer las disciplinas a través de su integración, teniendo en cuenta el papel fundamental de la enseñanza.

Palabras clave: Educación STEAM. Educación STEM. Discurso de la aprendización. Gert Biesta.

Introduction

Gert Biesta is a contemporary philosopher of education recognised for inquiring about prevailing educational discourses, assumptions, and practises (RØMER, 2021). He examines, for example, education as a teleological practice that stands for multidimensional intrinsic objectives (viz. *qualification*, *socialisation*, and *subjectification*)(BIESTA, 2020a). Furthermore, he sheds light on homogeneous discourses such as the tendency to focus the vocabulary on "learning"—e.g. "learning to learn', "learning environment", and "learning facilitator"—which, according to (BIESTA, 2015a), empties the discussions regarding content, purpose, and relationship in education.

In parallel, interdisciplinary approaches have been advocated in education following the underlying rationality that siloed knowledge areas cannot address complex issues of contemporary society (PERIGNAT; KATZ-BUONINCONTRO, 2019). Frequently under this tone, the interdisciplinary approach of Science, Technology, Engineering, Arts/Humanities and Mathematics (STEAM) has gained momentum in educational practice and research (MARÍN-MARÍN *et al.*, 2021; RODRIGUES-SILVA; ALSINA, 2023a).

Despite the enthusiasm, the literature advises that STEAM presents conceptual confusion and divergences that divert it to particular activities and contexts. Therefore, in previous works, we scrutinised STEAM education by reflecting on its distinctiveness as an educational approach. We proposed a framework of STEAM in a table format. Non-restrictively, teaching and learning configurations (table legs) and educational purposes (objects on the table) were understood as multiple elements that support (or are supported by) STEAM. Then we highlighted the most essential of STEAM through two necessary and sufficient conditions: interdisciplinarity and the disciplines comprising the acronym (table top) (RODRIGUES-SILVA; ALSINA, 2023a).

In the opposite direction of those efforts, we argue on the importance of contrasting the distinctiveness of STEAM by rationalising aspects which are not specific to it but comprehensive of all education. Accordingly, in this article's initiative, we delve into some of Biesta's ideas which broadly address education, and then we explore how those ideas could be reflected in STEAM. Beforehand, it is crucial to clarify that while taking Biesta's ideas up in this paper, we are not suggesting that he endorses or rejects STEAM education. Nevertheless, we pursue this enterprise because Biesta's educational theory makes inspiring reflections likely to encompass many current educational programs. Consequently, we are confident that Biesta's thoughts can enlighten some discussions around STEAM.

In this vein, we explore what Biesta (2019) refers to as the double history of the school and its consequent state of tension of purposes and configure the interplay between extrinsic and intrinsic goals of education. Then, we further (BIESTA, 2015a, 2021) analyse the *learnification* discourse, the three gifts of teaching and his proposal of returning the vocabulary from learning to teaching.

Subsequently, STEAM education through the prism of those ideas, we reflect on how the tension of purposes insides on this educational approach. Additionally, we reassess the *learnification* discourse in the context of STEAM. In this respect, we expand on the conceptual divergence in STEAM literature between transdisciplinarity and interdisciplinarity (RODRIGUES-SILVA; ALSINA, 2023a). Moreover, in parallel to returning the vocabulary from learning to teaching, we suggest redirecting the vocabulary from transdisciplinary to interdisciplinarity, wherein teaching could have a place.

Double history of schools and a tension of purposes

According to Biesta (2019), modern schools have a double history regarding the relationship between education and society. In the past, society had daily lives closely intertwined with work, such as in agricultural communities. In this case, children could learn all they needed (knowledge and skills) by directly interacting with this daily life and work. Thus, those societies had an intrinsic educative 'power' that permitted their renewal and continuity.

Notwithstanding, as Biesta (p. 661) asserts, 'society loses its intrinsic educative power' when work becomes more complex. From a certain point, newcomers cannot learn what they need by just experiencing daily life and work. Consequently, a unique institution is required to prepare those children to participate in such societies—to qualify and socialise to use Biesta's terms. In this angle of history, education is created with a clear role of servitude towards society. Accordingly to this function, 'society has legitimate expectations towards the school' and a 'legitimate right to check whether the school is giving society what it wants from it'.

From another perspective of history, schools are spaces between private and public life that shield children from society's demands. This school arrangement is congruent with the idea that newcomers must have time and space to grow before facing adult and political life. They need a safe environment that allows imagining, trying, making mistakes, and developing. In this setting, education does not have a subservient role toward society; instead, education intends to maintain a safe distance from it (ARENDT, 1958; BIESTA, 2015b; ROMÁRIO; RODRIGUES-SILVA, 2021).

Biesta (2019, p. 662) states that the referred double history of education culminates in a state of tension of demands. He says, 'There is a tension at the very heart of the modern school – a tension between the demand to be useful for society and a demand for keeping society at a distance.' Furthermore, protecting education from society's demands entails having a telos (*τέλος)* in Greek, which means purposes and agendas. Accordingly, (BIESTA, 2020a) claims education is a teleological practice with multidimensional purposes, viz. *qualification*, *socialisation* and *subjectification* (we will discuss those domains later).

In summary, the double history of education leads to a tension of purpose in the relationship between education and society. While society feels legitimate to set agendas and check school results, education must resist and withstand intrinsic purposes (telos), including keeping a distance from society's demands (BIESTA, 2015c). In addition to that, different sectors of society frequently pose contradictory demands. Eventually, education is accused of dysfunctionality when it refuses or cannot deliver what society asks, leading to a depiction of crisis in education.

Subsequently to the idea of crisis comes the urge for transformation and innovation toward the quality of education, an effective and efficient education (MARTINS; RODRIGUES-SILVA, 2022). Biesta explains that effectiveness and efficiency are neutral terms; the former refers to how well a practice accomplishes an objective, and the latter refers to how it utilises resources. Conversely, the word 'quality' is somewhat unquestionable (anyone would reasonably defend an education without it). Nonetheless, its underlying values are political questions with competing views of quality. Similarly, there is a problem of 'performativity', where organisations adopt quality indicators as the very definitions of quality for their strategic plans (BIESTA, 2019). Biesta (2022b) warns that while addressing a good education, the answer to—What is education for?—will likely forget the educative part. Consequently, in his words, 'there is a real possibility that education remains a toy of what "others" want from it' (p. 16).

Biesta (2015b) reports that an adaptive o survival discourse infiltrates research and practice of education. He suggests that we should alter the circumstances that generate the changing circumstances that require us to adapt.

> Survival is always about the question of what we need to do in order to adjust to changing circumstances. The key question we should always ask is whether those circumstances are the ones we should be adapting to or whether we rather need to 'invest' in altering the circumstances and the conditions that generate them (BIESTA, 2015b, p. 7).

Thus, considering the educative part of education, Biesta (2020a, 2015c) suggests education is a teleological practice with three purposes: *qualification*, *socialisation* and *subjectification*. He says *qualification* is about qualifying people to do certain things: transmitting and acquiring appropriate knowledge, skills and dispositions. Biesta clarifies that this 'doing' involves professional activities and preparing people to live in a complex world. Another purpose of education is *socialisation*, this domain relates to social structures, and it denotes initiating newcomers into ways of being and doing in communities, such as cultural, professional, political and religious traditions.

In addition to qualifying and socialising people, education also affects the student as a subject. Therefore, Biesta (2015c) defends that the third purpose of education is *subjectification*, which means calling students to exist as subjects with their own ends rather than mere objects of others' ends. Through this domain, students are called to exist as subjects who decide and take (or not) responsibilities in their personal, professional and political lives, including refusing to qualify and socialise, whether adapting or rebelling against a norm and society. The author highlights differences between *subject-ness* (what to do with what we are), identity (what we are) and subjectivity (what we think).

Moreover, Biesta explains that the three domains of education are not always in harmony. He argues that teachers' agency is necessary to make pedagogical decisions whether how and which purpose they should prioritise (BIESTA; PRIESTLEY; ROBINSON, 2015; SILVA; RODRIGUES-SILVA, 2022; RODRIGUES-SILVA; ALSINA, 2021). For instance, an activity conceived as a competitive environment might not be an excellent strategy to convey a sense of empathy in a community (socialisation), even though students learn a topic significantly (qualification). Also, authoritarian education may lead smoothly to strong socialisation into a culture and society, but it is likely not a proper form of calling students *subject-ness*, critical and autonomous thinking.

When Biesta (2015c) breaks down those three domains of educational purposes, he clarifies that the problem of the instrumental approach to education may be a matter of unbalanced focus on *qualification*. He argues that we need education for qualification: nobody wants attendance from an unqualified doctor. Nobody wants attendance from a doctor who is not socialised with the practices and codes of the medical community. Nobody wants attendance from a doctor who is not a subject of will and subjected himself to a hospital administration that only envisions profit.

Moving from learning to teaching

Biesta (2021) conceptualises *learnification* as a move in the educational discourse towards learning. In this sense, he identifies the arising of expressions such as "learning to learn", "learning environment", 'skills learning", and "facilitators of learning". Biesta explains that this discourse emerged from a contestation of an authoritarian approach which enacts the teacher as a dictator and teaching as indoctrination. However, he warns that *learnification* frequently has a one-dimensional focus on learning and overshadows purposes (*qualification*, *socialisation*, and *subjectification*) and other discussions in education, such as teachers' roles, content and relationships. He states:

> Language of learning to speak about and 'in' education, we have a language that often makes us 'forget' our responsibility as educators to always engage explicitly with content, purpose and relationships – which often means that decisions that should be made by those in the educational setting are already made by others, either in a very clear way or by default (BIESTA, 2015b, p. 3).

Biesta (2015a, pp. 235–236) positions that 'from the idea that learning is something natural, inevitable and unavoidable, it is only a small step to hear policymakers say that we, therefore, must learn.' According to that, research education pursues outcomes such as fostering students' talents by – facilitating and providing learning environments wherein students can direct and control their learning according to their wishes. Nevertheless, what is the content, and why are they learning? He says:

> As soon as we see that we all have talents to do good and to do wrong, as soon as we see that the moral life and the criminal life are both the outcome of developmental trajectories, we can no longer claim that education should just be about supporting the child's development, promoting the flourishing of all their talents so that they can reach their full potential (BIESTA, 2015b, p. 8).

Biesta (2022) has repeatedly affirmed that learning is not a distinctive aspect of education precisely because it can happen anywhere, with or without education. For instance, children working in factories in emerging countries learn a high sense of responsibility and cooperation at a very early age. However, there might be other aspects than learning in education that prevent us from suggesting forced child labour as an appropriate educational model.

Thinking about the distinctive part of education, Biesta (2015a) explores the relationship (if there is one) between teaching and learning. He offers reasons for keeping those concepts apart from each other. The first reason for this separation is to prevent the idea that we can understand teaching as an event that mechanically causes learning. In this sense, he argues that an educative action could initially be valued as good whenever it achieves what it intended to achieve (Biesta, 2022a, p. 26). However, this assumption is somewhat problematic: on the one hand, this idea suggests students are objects of intervention instead of thinking subjects; on the other hand, it deposits the entire responsibility of students' achievements on the teacher's shoulders.

Teaching and learning could be considered an intertwined relationship where those two concepts permeate inside each other. In that vein, Dewey compares teaching to selling commodities. He says, 'No one can sell unless someone buys'; therefore, no one could teach unless someone was learning (BIESTA, 2015a). Biesta (2015a) refutes this proposition as a necessary relationship between teaching and learning. While anyone can buy without a sale, people can learn without teaching (not necessarily affirming that every learning is possible without teaching).

For Biesta (2022b), teaching is a distinctive operation of education, so he defends that the educational discourse should invert the sense of *learnification* and move from learning to teaching. The word 'teach' in Latin is '*insignare*', which refers to giving a signal. Following this meaning, teaching is an 'evocative gesture' (p. 20) that involves presenting, pointing, and revealing. When someone teaches, he points out *something* to *someone*. By intrinsically existing someone (a subject) who decides whether to look or not, to give or not attention, teaching becomes a calling; teaching asks, or at best, demands attention. As a result, teachers may strive to capture students' attention, but they never have control over their students. Moreover, this inter-subjective dynamics breaks the causal relationship between teaching and learning.

Additionally, Biesta (2013, 2021, p. 48) explores three gifts of teaching. The first giving of teaching lies in the curriculum domain, which refers to 'being given what you didn´t ask for.' He argues that one rationale of education is to give students what they did not ask for because they did not know what they could ask. Biesta (2015a) reminds education goes beyond growing and deepening something already there. Education also is an encounter with the radically new, 'something that students precisely do not already have.' (p. 240). In other words, the outside world can address students with something they have no choice (since they are being addressed instead of being in a central position of constructing or making sense of the world), with no anchor points to connect with previous knowledge and perhaps unable to perceive a reason since this something is new to them.

If everyone naturally has the liberty to learn what they are willing for, according to Biesta (2021), the whole point of education – while gathering time, resources and people – is to provide something different that goes beyond those wills. Therefore, he positions the school as a place of revelation where the gift of teaching permits students to encounter and engage with things they were unaware of.

The second gift of teaching would be the 'double truth giving,' which lies in the domain of didactics. In this case, teaching means not just giving the truth but also relating to the format and how this giving may occur so that students have conditions of recognising it as truth as knowledge. Since students primarily unknowns the knowledge they are about to know, they cannot decompose it, select a proper order, and prioritise concepts and events, making it more palatable to be recognised as meaningful knowledge (BIESTA, 2021).

Finally, for Biesta (2021), the third given of teaching is 'being given yourself' and moves us towards the domain of subjectification. Our existence as subjects is about taking (or not) the responsibilities that cross our way. He concludes that this third gift goes beyond its intercessors. Therefore *subject-ness* is an act of emancipation wherein, as subjects, 'we are not just being given what we did not ask for, and not just being given the conditions under which we can recognise something as true or meaningful, but where we are being given ourselves, our *subject-ness'* (p. 50).

Biesta (2016, p. 10) dialogues *being taught* and *socialisation* stating that first encounters with culture are not subjective or interpretive matters, nor have they to do with an attempt to make sense of something. For him, this contact is a matter of being spoken to. The author reinforces his argument from a condition of anteriority. Before we 'decide' to receive/listen/pay attention, we are already being spoken to or 'being engaged in a conversation that has been going on before us'.

STEAM embedded in education

Accordingly, henceforth we address STEAM education considering Biesta's thoughts on education. Besides the evident instrumental approach associated with the very creation of STEM, this effort progressively was resignified in terms of intrinsic purposes of education. STEM, now better addressed as STEM education, evolved from an investment policy into a pedagogical approach centred on interdisciplinarity between the knowledge areas that comprise this acronym. One fundamental justification of STEM education is an actualisation of curriculum adjusted to the contemporary world (TANK; DUPONT; ESTAPA, 2020). Since the industrial revolution in the eighteenth century, technology and engineering have conquered a standing position in society. Accordingly, those areas become essential for contemporary personal, professional and political lives.

The forces of narrowing or widening educational programs relate to a tension of educational purposes. Biesta (2019, p. 657) states, 'all want something better from the school, although they disagree about what this may look like.' Bringing Biesta's ideas to the particular case of STEAM, there are many definitions of STEAM in the literature because researchers and practitioners defend different conceptions of STEAM according to various beliefs and views of education (PERIGNAT; KATZ-BUONINCONTRO, 2019). Researchers suggest STEAM models intending to provide a stable reference; however, those models are dissonant regarding teaching methodologies, educational goals, and forms of disciplinary relationship, viz., multi, inter, or transdisciplinarity (AGUILERA; ORTIZ-REVILLA, 2021). Moreover, usually, there is no reflection on whether having such a consensus is something positive for STEAM and education to an extent.

With this tension of demands in education in mind, now we remind the history of STEAM education. For that, first, we address the acronym STEM.

Initially, the National Science Foundation (NSF) coined this acronym in 1990 in the United States to refer to—and essentially justify—investments in the technological areas of science, technology, engineering and mathematics (CATTERALL, 2017). The central discourse around STEM was an urge for more scientists and engineers to develop economically in The United States of America (USA). Additionally, this country outlined STEM as a strategy for fostering technological superiority regarding warlike motivations. In this line, STEM is strongly related to the panorama of the cold war and the dispute between the USA and the Union of Soviet Socialist Republics (CHESKY; WOLFMEYER, 2015).

Another point to consider in favour of STEM is one of interdisciplinarity. Especially from modern science, humans have been continually creating knowledge (BORNMANN; HAUNSCHILD; MUTZ, 2021). The scientific practice ended up into an epistemological accumulation which tended, in the first moment, toward a process of specialisation: since people could not have a deep understanding of everything, knowledge needed to be increasingly partitioned and organised in areas and disciplines. However, in a second moment, this same epistemological accumulation gave the wisdom of the world's complexity. The specialised knowledge, perhaps hyper-specialised now, was shown to be incapable of approaching complex global issues such as environmental problems (FLORENTINO; RODRIGUES, 2015) and social inequalities (MEJIAS *et al.*, 2021). Scholars claim that various spheres of society need interdisciplinary approaches to articulate standpoints from different knowledge areas to understand and solve complex problems creatively and 'efficiently' (BOUFLEUER; MOURA, 2020).

STEM evolved into an educational approach, but representatives from other knowledge areas felt left aside regarding resources and curriculum space. Accordingly, they contested the focus on its four technological areas. As a result, STEAM was coined in 2007, immersed in this discontentment atmosphere. Supporters of STEAM intended higher valorisation of arts and humanities into the curriculum and during the budget sharing (PERIGNAT;

KATZ-BUONINCONTRO, 2019). This way, STEAM education is a wide-ranging educational program compared to STEM because it includes arts and humanities. Moreover, STEAM raises concerns such as sustainability (GUYOTTE, 2020) and gender equality (ROMÁN-GRAVÁN *et al.*, 2020). Furthermore, researchers claim STEAM develops critical thinking from a comprehensive perspective, including technical, artistic and humanistic outlooks (BASSACHS *et al.*, 2020).

As stated before, the political disputes between STEM and STEAM relate to what Biesta (2022b) identifies as contrary forces of continuous narrowing or widening educational programs. In that case, supporters of STEM and STEAM argue that the curriculum should incorporate technology and engineering in the face of the contemporary highly technological society (MOORE *et al.*, 2014). Additionally, they claim interdisciplinarity should prepare students to solve complex problems of the world creatively. The discourse about the urge for more scientists and engineers remains very active for both educational approaches (PERIGNAT; KATZ-BUONINCONTRO, 2019).

Society is constantly demanding the utility of everything that school teaches. Not without reason, researchers respond to this pressure doing contortionism to prove the applicability of a topic in the real world. For instance, in STEAM, many scholars attempt to justify Arts in the curriculum by displaying its benefits in 'helpful' abilities, such as creative thinking (PERIGNAT; KATZ-BUONINCONTRO, 2019). However, society overlooks educational rationalities, as Biesta (2015b, p. 2) states, 'The school also has something to do that is not automatically or necessarily useful for society.' In a similar effect, while adult life invades school with 'purposeful', or commonly said in STEAM literature, authentic activities (STROBEL *et al.*, 2013), playful pedagogies are systematically left aside with a running-out-of-time prerogative (RODRIGUES-SILVA; ALSINA, 2023b; SCHLESINGER *et al.*, 2020).

Nevertheless, there is a big step between what society requires from adults, and the knowledge areas schools should introduce in their curriculum.

The statement that—adults need knowledge from engineering and technology articulated with other areas so they can solve complex problems of the world— seems to be straightforwardly and unquestionably translated to children must do that as well.

There is a complaint that STEAM usually follows a subservient role toward society (CHESKY; WOLFMEYER, 2015). Indeed, STEAM repeatedly goes along with an adaptive discourse of acquiring knowledge and skills to respond to the demands of the labour market from a twenty-first-century society (NONG *et al.*, 2022). While STEAM claims to foster critical thinking, it usually overlooks being critical whether adapt or question those changes and their underpinning powers (BASSACHS *et al.*, 2020).

Equally, the adaptive approach regarding an ever-changing world might not be an exclusive phenomenon of STEAM. Likewise, the instrumentalisation observed in STEM and STEAM is not exclusive or particularly characteristic of those educational approaches. Biesta (2020b, p. 1025) says, 'As long as we think of education as merely a function of society, there is no way in which education can be defended when society, or powerful forces within society, decides to utilise it for particular ends'. On the one hand, we suggest not transforming STEM and STEAM as villains since the instrumentalised view happens to all education since it is not an exclusivity of those educational approaches. However, on the other hand, we claim we should challenge this instrumentalisation and offer alternatives by observing what happens in the breadth of education and its relationship with society.

Whereas a lack of consensus is alleged to be a problem in STEAM, we should perhaps be even more worried about homogeneous discourses around it. Retrieving Biesta's educational theory to frame the creation of STEAM, the author argues that a 'discourse of panic' creates a permanent sense of crisis in education and seems to drive into a relentless run for innovation and improvement (BIESTA, 2019). STEAM is regularly justified as a disruptive pedagogy that should overcome this so-called crisis (TOMA; GARCÍA-CARMONA, 2021).

Moving from transdisciplinarity to interdisciplinarity

We stated elsewhere that STEAM education frequently follows current educational tendencies such as active, authentic, meaningful, and collaborative learning (RODRIGUES-SILVA; ALSINA, 2023b). Following this, we argued that those extra elements should not be added to the definition of STEAM because they restrict this educational approach. Then we suggested a concise definition of STEAM through two necessary and sufficient conditions: the interdisciplinary approach and the five knowledge areas that comprise the acronym. Returning to this definition through Biesta's ideas, it is possible to identify a *learnification* discourse that permeates literature on STEAM education. As an effect, this discourse overshadows discussions in STEAM, such as interdisciplinarity, content from the five knowledge areas, teachers' roles, relationships, and the three domains of the purpose of education (*qualification*, *socialisation*, and *subjectification*) (RODRIGUES-SILVA; ALSINA, 2023a).

In STEAM, *learnification* discourse can be observed in the vocabulary used to address forms of integrating disciplines—multi, inter, and transdisciplinarity. First, clarify that these three concepts do not represent graduation but are totally different knowledge integration processes. Multidisciplinarity refers to disciplines working independently around a topic or problem. Interdisciplinarity refers to the integration of disciplines centred on the dialogue between them. In this case, the disciplines remain well-defined, their frontiers overlap, and their intersections are noticeable. Transdisciplinarity refers to a holistic approach where the knowledge areas are not defined and necessarily distinguished (BOUFLEUER; MOURA, 2020).

Transdisciplinarity usually is misunderstood as a higher level of integration of interdisciplinarity. However, we insist those concepts refer to different processes. In transdisciplinarity, disciplines' borders dissipate into a whole body of knowledge. In this case, disciplines are not distinguished because the focus is on the activity. Transdisciplinary is a natural way of experiencing and interacting with the world (QUIGLEY; HERRO; JAMIL, 2017). When students focus on understanding or solving any contextualised problem from the real or imaginary world, they tend to access the mesh of available knowledge and skills to address it, no matter the area or discipline they may belong to.

As stated before, Biesta (2015a, pp. 235–236) ascertains that policymakers move from 'learning is something natural, inevitable and unavoidable' to 'we must learn.' Now, we claim that this step is likewise to happen with transdisciplinarity. Since transdisciplinary is natural, inevitable and unavoidable, policy markers say we must have transdisciplinary learning. In this vein, we affirm that transdisciplinary follows the *learning* discourse.

However, transdisciplinary is a natural form of approaching an experience or activity that may occur anywhere. STEAM education—an educational approach that gathers resources, time, and people—might have something that distinguishes it from regular experiences in the world. In interdisciplinarity, contrary to transdisciplinarity, there is no intention of overcoming disciplines, but each discipline is expected to strengthen by the contact (dialogue) with the others. Additionally, since disciplines are human-socialised forms of interpretation and organisation of knowledge, they do not emerge spontaneously from natural experience with the world (FLORENTINO; RODRIGUES, 2015). Then if we aim to strengthen the knowledge areas of STEAM, this educational approach should intentionally call the dialogue between those areas, which is interdisciplinarity. In sum, STEAM outstands as education precisely when disciplines and their intersections can be retrieved (interdisciplinarity) to understand a problem that would be initially addressed diffusely (transdisciplinarity).

For that, we remind the three givings of teaching approached through interdisciplinarity. First, "Being giving what you didn't ask for": teachers should try to capture students' attention towards aspects of disciplines and their intersections which they were unconscious of during the activity. Second, “double” truth giving”: teachers should worry about the form of approaching knowledge (decompose, order, and prioritise concepts) so that students have conditions of recognising it as such from an activity. And Third, “being giving yourself”, teachers should recognise students as subjects and call them to *subject-ness*, make decisions and take responsibilities.

In other words, the distinctive educational part of STEAM is the teaching that plays a role of interruption/calling attention/pointing to the disciplines, their borders and intersections. As Biesta defend a move in educational discourse from learning to teaching, specifically to STEAM, we argue for a move from transdisciplinarity to interdisciplinarity.

Final discussions

Biesta’s philosophical orientation is critical and post-structuralist, reassessing dominant discourses while emphasising the role of language, power, and social conceptions (RØMER, 2021). Considering that Biesta’s educational theory inspires reflections on the breadth of education, we took up his ideas to explore tensions and homogeneous discourses around STEAM.

First, it helped to visualise that STEAM is circumscribed in broader discussions about education and its relationship to society. For instance, the instrumentalisation observed in the history of STEM and STEAM is not exclusive or particularly characteristic of those educational approaches—also, the lack of consensus on STEAM matches the variety of views about education. Moreover, various sectors of society differ upon what good education looks like. One example of such disparity is the bifurcation between STEM and STEAM, resulting from contrary forces of narrowing or widening educational programs—excluding or including arts/humanities.

As a specific educational approach, STEAM is crossed through discourses that permeate education, including the sense of crisis in education, a relentless claim for innovation, and the urge to adapt to an ever-changing world. Once we understand that all those discourses are not specifically from STEAM, we prevent demonising this educational approach and begin to challenge or envision different discourses. In this sense, we further analysed Biesta's concept of *learnification* discourse and his suggestion inverting the logic and moving the discourse from learning to teaching. Regarding STEAM, we observed *learnification* reflected in the idea of transdisciplinarity as a natural way of learning through activities. Accordingly, we articulated the three gifts of teaching in STEAM education. Following this, we suggested the parallel movement from transdisciplinarity to interdisciplinarity, wherein teaching has space, and the disciplines are strengthened through dialogue (FLORENTINO; RODRIGUES, 2015).

Commonly, literature on STEAM focuses on transdisciplinarity and learning (QUIGLEY; HERRO; JAMIL, 2017). *A posteriori* and just for scientific purposes, researchers dissect STEAM activities to analyse which knowledge areas supposedly emerged from that experience. Without doing or describing the teaching process, it is unclear whether the students were aware of those knowledge areas and intersections. As we have discussed elsewhere, explicitly addressing the disciplines is crucial, for example, to mitigate stereotyped perceptions related to some knowledge areas such as engineering (RODRIGUES-SILVA; ALSINA, [*s. d.*]). On the contrary, though transdisciplinary, they appraise learning happening without differentiating each discipline.

Thus, current research and practice in STEAM miss the teaching process of pointing to elements hidden in the transdisciplinary experience. In this regard, alongside teaching, teacher training can be essential so that designing STEAM activities can pursue the intrinsic objectives of education (RODRIGUES-SILVA; ALSINA, 2022). We argue that STEAM outstands precisely as education when disciplines can be retrieved to understand a problem that would be initially addressed diffusely. Accordingly, STEAM should consider teaching so the disciplines can dialogue and strengthen from their integration. Eventually, STEAM can be appropriately addressed as a proposal centred on the interdisciplinarity between science, technology, engineering, arts/humanities and mathematics.

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ARTICLE 3

STEM/STEAM in Early Childhood Education for Sustainability (ECEfS)

A systematic review

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Review

STEM/STEAM in Early Childhood Education for Sustainability (ECEfS): A Systematic Review

Jefferson Rodrigues-Silva [1,*] and Ángel Alsina [2]

1 Department of Mechanical Engineering, Federal Institute of Minas Gerais, Belo Horizonte 35588000, Brazil
2 Department of Subject-Specific Didactics, Faculty of Education and Psychology, University of Girona, 17004 Girona, Spain
* Correspondence: jefferson.silva@ifmg.edu.br

Abstract: We sought to explore the intersection between interdisciplinary STEM/STEAM educational approaches and Early Childhood Education for Sustainability (ECEfS). For that, we conducted a systematic review of Web of Science, Scopus, ERIC, and Scielo databases from 2007 to 2022 following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) commandments. The systematic search led to a list of 12 articles, and we analysed them through theoretical orientations, educational perspectives, and pictures of children's nature. We found that most studies focus on sustainability's environmental pillar and address the discipline of science more frequently. Additionally, the authors tend to assume a theoretical orientation on the need for connecting children to a sustainable issue and picture the Apollonian child—assuming children are essentially good and emerge with virtuous traits from this contact, such as environmental care. Accordingly, researchers usually propose experiential learning in environments or settings related to sustainability, while there is a lack of teaching STEM/STEAM knowledge and skills on sustainability or engaging children to act for sustainability. We verified that they frequently lose opportunities to explicitly discern STEM/STEAM knowledge areas and their intersections in moments that could benefit children's learning.

Keywords: STEAM education; STEM education; sustainability; environmental education; early childhood education

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1. Introduction

International organisations have published several reports on the necessity of environmental protection [1,2] and the urge for a sustainable society [3–5]. Accordingly, education has been summoned to participate in this global challenge that sustainability represents [5–7]: being sustainability conceived as a complex and entangled concept comprising a triad of social, environmental, and economic aspects [3]. In this context, education is portrayed as a critical motor and an outcome of sustainability. First, Education for Sustainability (EfS) is argued as necessary to develop students' knowledge, values, agency, and actions that lead to a sustainable society [5]. Second, quality education for all is recognised as a Sustainable Development Goal (SDG) [5], since it is related to, for example, having access to good jobs and advancing social and gender equity [8].

On the one hand, considering education as a motor for sustainability, United Nations Educational, Scientific, and Cultural Organization (UNESCO) [7] argues for reorienting education to sustainability through interdisciplinarity pedagogy. Following this idea, in 2018, they mentioned the interdisciplinary approach of Science, Technology, Engineering, Arts/Humanities, and Mathematics (STEAM) education for achieving SDGs [9]. On the other hand, considering education an outcome of sustainability, interdisciplinarity is argued as a pedagogical strategy to enhance quality education. Jamali, Ale Ebrahim, and Jamali [10], for example, conducted a bibliometric study of the terms "STEM education"—an interdisciplinary educational approach between Science, Technology, Engineering, and Mathematics—and "quality education" reflected in publications from 1993 until 2000.

They concluded, through an analysis of keywords, that "STEM education" and "Early Childhood Education" were growing intensely [10]. At this point, we clarify that the STEM and STEAM approaches differ regarding the education scope. Respectively, they represent the concentration of efforts on technological knowledge areas or the inclusion of arts and humanities [9,10]. In this study, we mention them not as interchangeable approaches, but we focus on their accordance with interdisciplinarity's role in enhancing education. For example, Varela-Losada et al. [11] pursued a bibliometric analysis in transformative learning for sustainable development. The authors detected the central cluster of closely-related terms to sustainability: critical reflection, social learning, and transdisciplinary/holistic education.

While EfS is defended throughout all educational levels [12], some reports highlight the contribution of Early Childhood Education (ECE) to sustainability [13,14]. The particular interest in early childhood—birth to eight—embraces the rationality that initial ages are foundational for environmental sensitivity, literacy, and behaviour later in life [15]. Furthermore, children are recognised as subjects owning the right to have an opinion about aspects that impact their lives, including sustainability issues [12,16].

Accordingly, literature reviews have focused on Early Childhood Education for Sustainability (ECEfS) [12,16,17]. For example, Davis [17] reviewed articles between 1996 and 2007. He evidenced that educators' interest in sustainability was becoming apparent in this period. Somerville and Williams [16] reviewed studies published between 2003 and 2009, and Yıldız et al. [12] covered articles published between 2008 and 2021. Together, those studies help to draw a longitudinal understanding of ECEfS. They confirm an increasing interest in ECEfS and primarily positive outcomes observed in empirical studies. Notwithstanding, those reviews demonstrated that researchers' attention to sustainability had been minimal in ECE, and the field lacks the necessary foundation and critique [12,16,17].

Despite the demands from society towards education to engage with sustainability, it is worth bearing in mind the intrinsic objectives of education [18,19]. Therefore, we propose inverting the logic from "Education for Sustainability" to "Sustainability for Education" and wonder about sustainability's contribution to education, specially addressed through interdisciplinary approaches in ECE. Evidence shows, for example, that STEM and STEAM strengthen children's agency and cognitive, attitudinal, and emotional abilities [20–22]. Moreover, researchers have stressed that students develop knowledge and abilities in STEM education while addressing ECEfS [23,24]. Reviews confirm the connection between EfS and interdisciplinarity [10,25]. However, no previous reviews have specifically addressed the intersection between ECEfS and interdisciplinarity.

Minding this research gap, we sought to conduct a review that explores the intersection between Early Childhood Education for Sustainability (ECEfS) and STEM/STEAM education.

2. Theoretical Framework

Following the research objective, we theoretically scaffold Early Childhood Education for Sustainability (ECEfS) and STEM/STEAM education. Next, we address the main discourses and theoretical orientations on those topics.

2.1. Early Childhood Education for Sustainability (ECEfS)

According to the Population Division from the Department of Economic and Social Affairs (DESA) of the United Nations [26], on 15 November 2022, the world's population reached 8 billion people. Over the last century, the planet has experienced rapid population growth. For example, the move from 7 to 8 billion inhabitants took only 12 years to accomplish [27]. Even though the predictions indicate that this growth rate is slowing [27], human presence and activity have been so dramatic to the planet that researchers recognised the Anthropocene—a new geological era imprinted by humankind as the leading natural force with global implications [28–30].

In 1987, the World Commission on Environment and Development (WCRD) published the Report Brundtland, "Our Common Future", framing sustainability in terms of human temporality [3]. This document defined sustainable development as the ability to meet today's needs without compromising the ability of future generations to meet their needs. According to UNESCO [7] (p. 17), sustainable development "is not a fixed notion, but rather a process of change in the relationships between social, economic, and natural systems and processes". It is a complex concept where social, environmental, and economic pillars intertwine [6,7]. Consequently, sustainability requires many spheres of society to engage with it. Moreover, sustainability entails multiple and integrated knowledge areas to comprehend the world's complexity and provide creative solutions [7,31,32].

International reports have demanded education to engage with the endeavour of a sustainable future [12]. In brief, EfS is claimed to empower students to be subjects who make informed decisions to promote the well-being of current and future generations [25]. Accordingly, those discourses on the necessity of engaging education with sustainability have echoed at all educational levels [12], including the preschool period. Early childhood is critical for a sustainable life because values, attitudes, behaviours, and skills are cultivated in this phase [13]. In Figure 1, we present a timeline of international reports on fostering ECEfS and conducting STEAM education as an appropriate interdisciplinary educational approach for sustainable development.

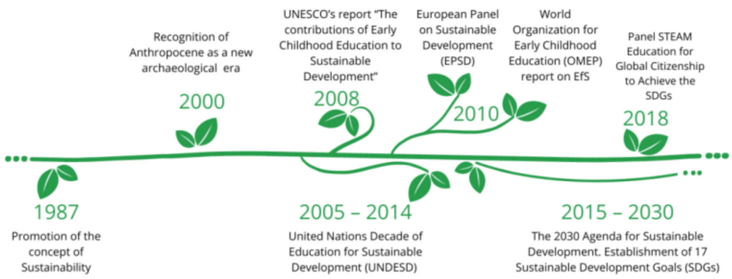

Figure 1. Timeline of international reports related to fostering Early Childhood Education for Sustainability (ECEfS) and STEAM education.

As stated before, Brundtland's [3] report reinforced sustainability as a comprehensive concept encompassing environmental, sociocultural, and economic pillars. Next, according to environmental concerns [1,2], Anthropocene was recognised as a new geological era imprinted by humans as the main nature force that impacts the planet [28–30]. The need for change is reflected in many actions. For example, UNESCO [6] established 2005–2014 as the United Nations Decade of Education for Sustainable Development (UNDESD). Within this period, some arrangements focused on the preschool level, for instance, UNESCO's workshop named "The hole of Early Childhood Education for a sustainable society", held in 2007 [13]. The European Panel on Sustainable Development (EPSD) was held in 2010 [16]. This same year, the World Organization for Early Childhood Education delivered a report indicating that sustainability includes children's right to have an opinion on sociocultural, economic, and environmental issues [12].

In 2015, United Nations set 17 Sustainable Development Goals (SDGs) in the Agenda 2030 [5]. Early Childhood Education (ECE) and Education for Sustainability (EfS) were articulated among those goals. Goal 4.2 stated that all girls and boys have access to quality early childhood development, care, and pre-primary education. Moreover, Goal 4.7 referred to the commitment to "ensure that all learners acquire the knowledge and skills needed to promote sustainable development, including, among others, through education for sustainable development and sustainable lifestyle." As a final point to the timeline, a panel focused on STEAM education as an interdisciplinary approach appropriate for achieving the SDGs [9].

2.2. STEM/STEAM Education

We further on STEM and STEAM education, initially, because those interdisciplinary approaches have been defended as relevant pedagogy to reorientate education for sustainability, but, then, we emphasise sustainable issues as authentic contexts that may contribute to developing children's STEM/STEAM literacy [22].

The acronym STEM was coined by the National Science Foundation (NSF) in the United States in the 1990s to refer to and justify many educational policies focused on the development of professionals in the areas of Science, Technology, Engineering, and Mathematics [32–34]. First, the central rationality behind STEM was qualifying professionals considered essential to national competitiveness, considering economic and warlike development [33]. Afterwards, educational practitioners and researchers resignified STEM into a pedagogy of interdisciplinarity between the knowledge areas that comprise the acronym. In 2007, STEAM emerged in the United States as there was discontent with the STEM focus on technical knowledge [34,35]. In this sense, STEAM represents a competitor research line. This new acronym differentiates by including the letter A—meaning arts and humanities—and, therefore, demanding a broader curriculum scope than STEM [32].

Despite the differences, STEM and STEAM are educational approaches centred on interdisciplinary teaching [36,37]. They are currently prominent educational practices and research approaches [38] that have been adopted in many countries, such as the United States [39], Korea [40], and Spain [41]. Both educational approaches are usually associated with meaningful (scaffolded in previous knowledge [42]), active (involving students' actions [43]), and authentic (contextualised in natural settings [44]) learning. In this sense, they are usually conducted through active teaching methodologies such as project/problem/inquiry-based learning and aligned with playful learning [45], such as in free or guided play [46,47], games [48], and gamification [35].

Incorporating Engineering and Technology is quite distinctive of STEM and STEAM education, since these knowledge areas were commonly absent in the pre-college curriculum [49–51]. One point that unifies STEM/STEAM and sustainability is the significant role of engineering and technology professionals in pursuing solutions towards an ecologically resilient, socially just, and economically viable society [11].

Furthermore, inverting the rationality from "Education for Sustainability" to "Sustainability for Education", the authenticity of sustainable issues provides a rich context for meaningful learning in STEM/STEAM. Usually, those educational approaches integrate the knowledge areas that comprise each acronym through authentic contexts [52]—a sustainable issue, in this case. Hormazábal, Rodrigues-Silva, and Alsina [20], for example, reported an activity in primary education where children applied statistics to analyse conceptions about engineers from their drawings. They perceived and discussed the tendency to picture male engineers. Chen and Liu [25] reviewed studies on EfS and observed that the literature increasingly explores the relationship between interdisciplinarity and sustainability. They verified that between 1997 and 2010, only five articles promoted students' participation in sustainable action under interdisciplinary pedagogical frameworks. In contrast, from 2010 until 2007, 18 studies enrolled in interdisciplinary activities. According to them, students were empowered by working with interdisciplinarity while addressing authentic problems. After 2010, they specifically remarked on increased science and art studies. However, their study is somewhat limited regarding young children, because only 3 of the 34 documents reviewed concerned ECE.

At this point, we recall United Nations' [9] emphasis on STEAM to achieve SDGs. Accordingly, we clarify our perspective towards STEAM by stating that the complex triad of social, environmental, and economic pillars is better addressed if it encompasses knowledge and skills beyond the STEM technical areas.

2.3. Discourses in Early Childhood Education for Sustainability (ECEfS)

As presented above, sustainability enters educational practice and research remarkably as an external demand of society. As a following step, education may recognise teleological rationalities [19], such as perceiving educational opportunities for interdisciplinary learning around sustainable issues [29]. Many discourses intertwine within education and sustainability regarding different theoretical orientations [16], educational perspectives [17], and pictures of children's nature [28].

Somerville and Williams [16] observed three theoretical orientations provided as critique in sustainability discourse: connection to nature, children's rights, and posthuman. The connection to nature orientation affirms that children should have experience in natural environments from early years to grow healthy and develop environmental care [16]. This idea is commonly encouraged by a "nature deficit disorder" concern [53] (p. 34). There is a complaint that children are immersed in technological and urbanised environments, as if they were detached from the natural world. Such disconnection would result in their disengagement from nature. The children's rights orientation states that very young children are capable of sophisticated thinking and should be recognised as subjects with the right to have an opinion about issues that impact their lives, such as sustainability [12,16]. In this vein, education should foster children's citizenship with recognised rights and responsibilities related to daily practices considered relevant to sustainable development. Consequently, children are recognised as active agents [12], and pedagogies supported by this rationality usually foster education through child-led practices. Finally, the third theoretical orientation, posthuman, criticises the centrality of humans regarding others as cohabitants on the Earth. Moreover, it suggests moving beyond the dilemma of nature and culture [54]. Frequently, researchers in this paradigm align with decolonising enterprises that value some indigenous traditions, such as ethnomathematics, which fuses nature and culture and humans and non-humans [55,56].

In terms of educational perspective, Davis [17] distinguishes between education in, about, and for the environment. Similarly, we translated those distinctions to sustainability. The educational perspective education in sustainability is centred on providing children with an experience in a sustainable aspect, education about sustainability is centred on developing knowledge about a sustainable aspect, and education for sustainability is centred on engaging action for a sustainable aspect. Those educational perspectives may be entangled and complement each other (as discussed later) in pursuing Education for Sustainability (EfS). We clarify that we distinguish the educational perspective of education for sustainability from the broader aim, capital letter Education for Sustainability.

Discourses around sustainability in ECE commonly draw pictures of children's nature. In this sense, Sjögren [28] used two images of children and childhood, the Dionysian child and the Apollonian child. The former image refers to the understanding of children as originally corrupted and inclined to harbour evil. The latter depiction considers children as born good and with a unique potential, which should be facilitated and encouraged. The author remarks that, although being just categorical depictions, they are robust theoretical frames for practices in ECE. Additionally, he points out that western discourse on children's nature, at first glance, tends towards the Apollonian image. However, the Dionysian image is constantly "somewhere lurking alongside" [28] (p. 04).

Additionally, we observe that the Anthropocene concept is well aligned with the posthumanist theoretical orientation. Anthropos reinforces the idea of referring to humans as one of many biological species on Earth—despite their significant impact on the current geological period [28,30]. Anthropocene has entered educational discussions [29], including early childhood [28]. Guyotte [29] (p. 07), for example, advocates for a philosophy of STEAM in the Anthropocene. This regard through the Anthropocene widens the scope of this educational approach in light of global issues, particularly the urge for sustainability. She posits that "sustainability issues and related power networks are non-linear, complex, and often irrational". Following, the author argues that STEAM education creates spaces where disciplines come together in dialogue; she says, "[i]n STEAM education at all levels, students should be exposed to the many complex and urgent issues of the Anthropocene—issues that are inter- and transdisciplinary in nature" [29](p. 07). Through a critical revision of studies addressing the Anthropocene in ECE, Sjögren [28] found the tendency in the literature to romanticise children as essentially different from adults—since young children are less likely to have incorporated the humanist detachment of humans and nature, they could offer insights regarding illuminating wildlife that adults rarely could access.

3. Methods

Bearing in mind the ambition of exploring the intersection between ECEfS and STEM/STEAM education, we enrolled in a literature review following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statements. Accordingly, the review process is structured and informed to guarantee reproducibility [57]. The review is organised into four phases: (1) search elements and Boolean logic, (2) eligibility criteria, (3) information sources, and (4) data collection and analysis.

3.1. Search Elements and Boolean Logic

First, we identified the central terms of the research goal: "sustainability", "STEM", "STEAM", and "Early Childhood Education". Similarly to previous research in ECEfS, we encompassed "environmental education" [16,17] and early childhood settings such as nature, bush, or forest schools [15]. Eventually, while considering synonyms, we resulted in the string: (STEM OR STEAM) AND ("Early childhood" OR "early education" OR "early years" OR preschool OR kinder* OR "Initial education" OR "nursery education") AND (sustainab* OR environmental OR bush OR forest).

3.2. Eligibility Criteria

Table 1 presents the eligibility criteria applied to this review. We included documents available in English because this language is primarily used in educational research. Likewise, documents written in Spanish and Portuguese were considered to take advantage of the authors' proficiency in those idioms and enlarge the study's geographical coverage as much as possible.

Table 1. Eligibility criteria.

Criteria	Inclusion	Exclusion
Language	English, Spanish, and Portuguese	Other languages
Publication period	From 2007 to 2022	Before 2007
Type of document	Peer-reviewed article	Other formats
Research area	Education	Other areas
Level	Early Childhood Education (ECE)	Other levels

We considered documents published from 2007—because the acronym STEAM was coined this year [32,35]—until November 2022. Another reason is that this time, likewise, encompasses the period posterior to UNESCO's [13] report "The contributions of Early Childhood Education to Sustainable Development".

Next, we set the type of document criteria to include only peer-reviewed documents. Although we recognise that the peer-review process might sometimes be inconsistent, it suggests some research quality [15]. Finally, we included articles from educational research centred on ECE—from born to eight years [15]. The exclusion criteria were essentially antonyms of the inclusion ones.

3.3. Information Sources

In this third phase, we selected Web of Science (WoS), Scopus, Education Resources Information Center (ERIC), and Scielo databases because they are recognised for their rigour and importance in research, particularly in the educational field.

3.4. Data Collection and Analysis

Once we established the Boolean logic, we used it to scan documents' titles, abstracts, and keywords. Some adaptations were necessary, according to the coding from each database. For instance, the string was simplified in ERIC because it is a specific index from the educational field and presents a filter on the educational level. It permitted restricting the search to documents registered in ECE. As shown in Figure 2, the initial search resulted in 315 records. We used the platform's filters to apply some eligibility criteria such as language, publication period, type of document, and research area. Next, data were exported from those index platforms and gathered into an Excel spreadsheet. Then, we excluded repeated documents by comparing articles' titles or Digital Object Identifier (DOI) numbers. Following, we read abstracts and full texts. At this point, we excluded articles that did not meet the eligibility criteria, such as those focused on other educational levels instead of ECE. Similarly, we excluded some articles that did not mention STEM or STEAM education, such as when the term "STEM" led to documents with the word "system" or when "STEAM" was scanned in studies meaning "vapour".

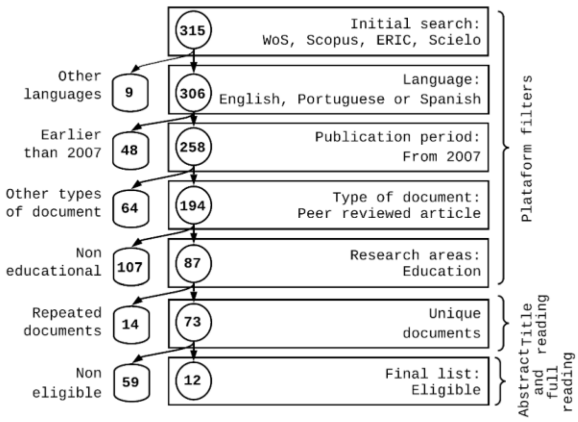

Figure 2. Data collection process flowchart.

The article "Mathematics learning in the early years through nature play" [58] seemed to accomplish the inclusion criteria, but it had to be excluded because we could not access the complete document. We contacted the authors, but they did not answer back. We highlight that other articles from the same authors are reflected in this review, so their visions are somehow already considered.

Eventually, the data collection process led to a final list of 12 eligible documents.

Afterwards, we proceeded with the analysis of the selected documents. First, we uploaded them into the Atlas-ti program for accounting word occurrence. Then, we plotted this information in a word cloud to provide an overview of the main terms in the articles as a group of documents. Then, we observed those terms regarding the Boolean logic, eligibility criteria, data collection process, and analyses a posteriori.

Following, the data analysis occurred through fluctuant readings to ascertain central topics. Then, we followed with in-depth readings and proceeded with multiple comparisons through categories deducted from the literature while permitting new categories to emerge from the data. First, we explored general research features such as publication year, region, sample, age, population, method, intervention, duration, design, and data collection instrument.

Subsequently, we explored the topics that directly involved ECEfS and STEM/STEAM education. Although sustainability is a complex concept that intertwines social, environmental, and economic aspects [6,7], we identified whether the study focused on one of them. In this case, the environmental dimension relates mainly to issues such as pollution, mitigation of climate change, and conservation of natural resources. The social dimension includes respect for human rights, cultural diversity, health, social equity, and governance. Finally, the economic dimension recalls concern about issues such as poverty alleviation; fair access to human, natural, and financial resources; and corporate ethics, responsibility, and accountability [7].

Next, we classified which educational approach the authors positioned, STEM or STEAM, and the knowledge areas explicitly articulated in each study. As already defined in the theoretical framework of this study, we discussed the theoretical orientations: connection to nature, children's rights, and posthuman [16]; educational perspectives: education in sustainability, education about sustainability, and education for sustainability [17]; and children's pictures: Dionysian child and Apollonian child [28].

4. Results

We start the result topic by presenting a word occurrence analysis of the manuscripts in a word cloud format, as shown in Figure 3. The words "children", "education", and "learning" appear in the spotlight of the image and indicate that the selected papers, as a group of documents, concern educational research. Additionally, the words "kindergarten", "kinder", "preschool", "childhood", "early", and "young" assert that they are centred on young children. In addition, the word cloud highlights the educational approaches "STEM" and "STEAM", with a more substantial occurrence of "STEM" than "STEAM". Finally, the expressions "sustainable" and "sustainability" appeared as well.

Figure 3. Word cloud of articles on STEM/STEAM education in Early Childhood Education for Sustainability (ECEfS).

Still referring to the word cloud, we should note that "sustainable" and "sustainability" had a relatively low emphasis in comparison to other elements of the research. If we observe environmental, social, and economic pillars, the terms "environmental", "nature", and "bush" point to the environmental aspects. In this line, the words "social" and "girls"—we will see that specifying girls relates to gender equity concern—indicate addressing social aspects. Finally, the word cloud did not display economic-related terms such as "viability", "economy", and "cost". This non-occurrence suggests that the economic pillar of sustainability might be absent in those studies.

Table 2 lists the reviewed articles and presents research features. In advance, we remark that the low number of documents in this review—only twelve articles—already is a result that indicates the scarcity of studies on the intersection of ECEfS and STEM/STEAM education. Moreover, it confirms the tendency observed in other reviews on EfS that research in ECE is overlooked compared to other educational levels [16,17]. In the following paragraphs, we further explore information from this table.

Table 2. General research features.

Author	Year	Region	Sample	Age (Year)	Population	Method	Intervention	Duration	Design	Instrument
Aladé et al. [59]	2022	USA	48	5 to 7	Children	Mixed	STEM-focused television series	Eight weeks	Pre-post with a control group	Interview and questionnaire
Bascopé and Reiss [60]	2021	Chile	24	4 to 10	Teacher	Qualitative	Planning and implementing STEAM	One year	Ethnography	Interview
Borgerding and Kaya [61]	2018	USA	-	3 to 6	Children	Qualitative	Interactive yarn stories	One week	Case study	Field notes and image placement assessments
Campbell and Speldewinde [23]	2022	Australia	240–300	4 to 5	Children	Qualitative	Bush school	Three years	Ethnography (longitudinal)	Field notes, interview, video recording
Carr and Luken [62]	2014	USA	-	-	Children	Qualitative	Playscapes	-	Narrative review	-
Gurjar [63]	2021	Italy	-	-	Children	Qualitative	Maker space	No	Cross-sectional	No
Monkeviciene et al. [64]	2020	Lithuania	1232	-	Teachers	Quantitative	-	-	Cross-sectional	Questionnaire
Nong et al. [65]	2022	China	242	-	Teachers	Quantitative	-	-	Cross-sectional	Questionnaire
Speldewinde [66]	2022	Australia	80	4 to 5	Children	Qualitative	Bush school	One year	Ethnography (longitudinal)	Field notes and interview
Speldewinde and Campbell [67]	2021	Australia	80–100	4	Children	Qualitative	Bush school	Five years	Ethnography (longitudinal)	Field notes, interview, video recording
Speldewinde and Campbell [24]	2022	Australia	100	4 to 5	Children	Qualitative	Bush school	Five years	Ethnography (longitudinal)	Field notes, photo, interview
Spiteri et al. [68]	2022	Malta	9	3 to 7	Children	Qualitative	-	-	Multiple case studies	Interview and drawings

In Figure 4, we present the publication distribution time of the documents. Although we had set the timespan from 2007 to 2022, we only found articles published from 2014. Additionally, the graph shows a growth tendency from 2020, while the number of documents published doubled between 2021 and 2022. Accordingly, the time distribution shows that the intersection of ECEfS and STEM/STEAM education occurred very recently and is experiencing an uprising of interest. First, this result follows tendencies observed in general reviews on ECEfS, indicating a more significant number of studies published in the last years [12]. Second, it reflects the strengthening of STEM [10] and STEAM [38] as research lines. Moreover, United Nations [7–9] reports demanding a redirection of education towards sustainability and explicitly mentioning interdisciplinarity are expected to foster the intersection of ECEfS and STEM/STEAM education in the following years.

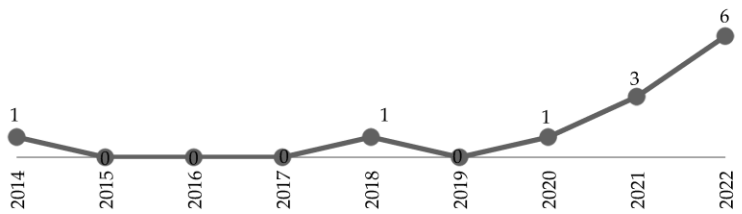

Figure 4. Publication distribution time of articles on STEM/STEAM education in Early Childhood Education for Sustainability.

In terms of geographical distribution, as presented in Figure 5, the reviewed studies were enrolled in Chile [60], China [65], Italy [63], Lithuania [64], Malta [68], and the United States [59,61,62]. Moreover, Australia concentrates on four documents authored by Campbell and Speldewinde [23,24,66,67]. Those authors explored different aspects of STEM education in bush schools: an out-of-class setting fostered in this country wherein children experience the natural world mainly through playful activities [66] (we will discuss it later).

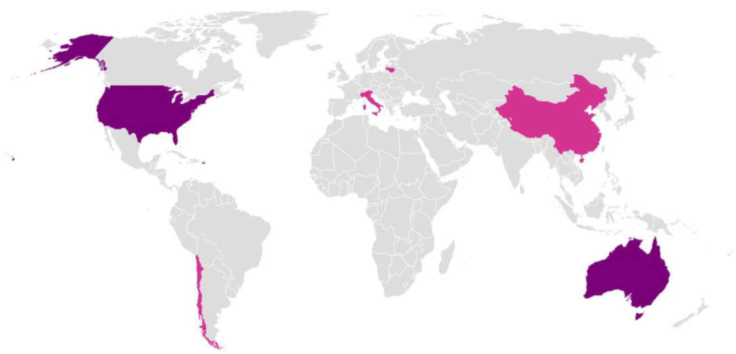

Figure 5. Geographical distribution of articles on STEM/STEAM education in Early Childhood Education for Sustainability (image created with Datawrapper).

Most studies (9) have children as their research population. Only three studies focused on teachers [60,64,65], while no research addressed other related groups, such as family members. Considering exclusively the reviewed articles that focused on children, we analysed children's age into four equal intervals of two years, embracing the whole childhood (0–8 years). Whenever research encompassed children from more intervals, they were counted multiple times. Carr and Luken's [62] study was not accounted for because they addressed playscapes and did not specify age. Figure 6 shows that most studies investigated children aged between four and six (7). We remark that no study addressed children younger than two years old.

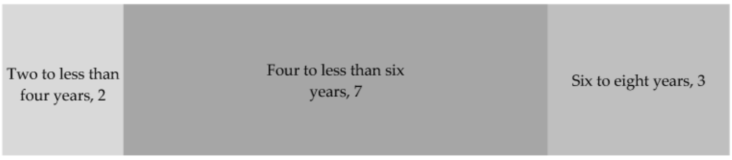

Figure 6. Children's age distribution.

The research method mostly followed a qualitative approach (9). Campbell and Speldewinde [23,24,66,67] pursued a similar methodology in their four studies. Those authors enrolled in ethnographies during repeated visits to bush schools for 1 to 5 years. Agreeing with ethnographies, which commonly use different sources of information, they used field notes, sometimes interviews, and image recording. Their research design can be understood as longitudinal regarding the evolution of the schools, but they did not accompany children's temporal changes. Aladé et al. [59] published the only mixed-method research. They enrolled a pre-post design with the control group using interviews and questionnaires to evaluate the effects of a counter-stereotypical STEM-focused series on children's mental schemes of STEM professionals.

Regarding the studies focused on teachers as a research population, Monkeviciene et al. [64] and Nong et al. [65] conducted quantitative research through the application of a questionnaire in a cross-sectional design, which means data were collected only one time [69]. Differently, Bascopé and Reiss [60] focused on teachers, but through qualitative research. They pursued an ethnographic study for a one-year programme of planning and executing STEAM activities on sustainability.

Henceforth, we explore topics specific to STEM/STEAM and ECEfS. In Table 3, we display the articles' theoretical orientations, children's pictures, educational perspectives on sustainability, and sustainability pillars. Additionally, we present which educational approach (STEM or STEAM) the authors adopted and the STEM/STEAM knowledge areas they explicitly addressed. We present each study's primary outcome or result in the table's last column.

Table 3. STEM/STEAM education and Early Childhood Education for Sustainability.

Author	Theoretical Orientation			Children's Picture		Educational Perspective on Sustainability			Sustainability Pillar			Educational Approach		Explicit Knowledge Area					Main Outcome/Result
	Connection	Children's rights	Posthuman	Apollonian	Dionysian	In	About	For	Environmental	Social	Economic	STEM	STEAM	S	T	E	A	M	
Aladé et al. [59]	x			x		x				x		x		x	x	x		x	Children's occupational schemes had no quantifiable change before and after exposure to a counter-stereotypical STEM-focused series.
Bascopé and Reiss [60]	x	x				x	x	x	x	x	x	x		x					STEM projects fostered collaborations of teachers with local actors and organisations usually sidelined from educational experiences. The authors summarised examples of meaningful learning experiences to tackle sustainability challenges.
Borgerding and Kaya [61]			x			x	x		x				x	x			x		Children used teleological reasoning to explain why particular organisms lived in particular environments. They succeeded at placing organisms' images corresponding to three different biomes.
Campbell and Speldewinde [23]	x	x		x		x			x			x		x					Children learned STEM abilities, such as problem-solving, scientific thinking, agency over the language of science, and environmental understanding in bush kinder.
Carr and Luken [62]	x											x							The study discusses the value of play and the environment to wonder about the natural world and precede teaching about the environment and STEM disciplines.
Gurjar [63]		x		x		x			x			x		x	x				Recognition of pedagogical potentialities of maker space with natural and recyclable material. E.g., learning STEM concepts and fostering children's self-efficacy in design.
Monkeviciene et al. [64]	x	x		x		x	x	x					x	x	x	x	x	x	ECE teachers developed STEAM activities targeting soft skills (problem-solving, creativity, communication) more frequently than concepts and abilities specific to the STEAM disciplines.
Nong et al. [65]													x	x	x	x			Short videos positively affected teachers' students STEAM learning performance and sustainable inquiry behaviour.

Table 3. *Cont.*

Author	Theoretical Orientation			Children's Picture		Educational Perspective on Sustainability			Sustainability Pillar			Educational Approach		Explicit Knowledge Area					Main Outcome/Result
	Connection	Children's rights	Posthuman	Apollonian	Dionysian	In	About	For	Environmental	Social	Economic	STEM	STEAM	S	T	E	A	M	
Speldewinde [66]	x			x		x			x			x		x	x	x		x	The study resulted in a five-phased cyclical conceptual model on STEM teaching and learning in Early Childhood Education (ECE).
Speldewinde and Campbell [67]	x			x		x			x	x		x		x	x	x		x	Bush kinder settings allowed young girls to develop STEM identities through social interactions and fostered STEM learning.
Speldewinde and Campbell [24]	x			x		x			x			x			x	x			Bush kinder could develop children's technological and engineering knowledge.
Spiteri et al. [68]				x			x		x				x	x			x		Children perceived the environment as nature, consisting of different elements of flora and fauna found in the Maltese Islands.

As shown in Figure 7, the environment is the primarily addressed pillar of sustainability (7), followed by social (3) and economic pillars (1). The social aspect concerned exploring the effects of a counter-stereotypical STEM-focused series [59] and gender equity [67]. Continuing to refer to the social pillar, Bascopé and Reiss [60] implemented a teacher training programme involving STEM projects interacting with local communities (Mapuche) and traditions from the south of Chile. Those authors observed that the STEM implemented by the teachers similarly tended to focus on environmental issues. One project from this teacher training programme exhibited an economic vein by connecting local food entrepreneurs and a food showcase. At this point, we mention that the low presence of the economic pillar confirms the previous suggestion in the word cloud by the non-occurrence of economic-related terms.

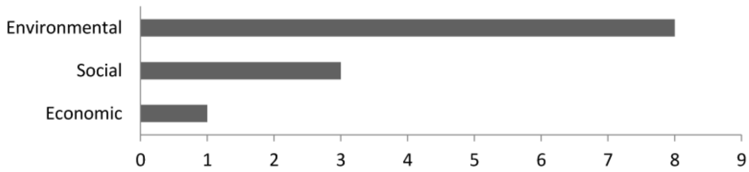

Figure 7. Sustainability pillars in articles on Early Childhood Education for Sustainability (ECEfS).

Regarding the educational approaches STEM or STEAM, as the word cloud suggested, STEM (8) was more frequently approached in the studies than STEAM (4). In this sense, we point out that, although STEAM is growing as a research line, it is newer and generally less noticeable than STEM education in the literature [38]. In Figure 8, we account for STEM/STEAM knowledge areas the authors explicitly addressed in the studies (not meaning that they were made explicit to children). We did not count areas called out only to refer to the ensemble of fields, such as while explaining the acronyms STEM and STEAM. As a result, science stands out as the discipline mainly addressed. Equally, Monkeviciene et al. [64] found that ECE teachers in Lithuania prioritised science over the other STEAM fields.

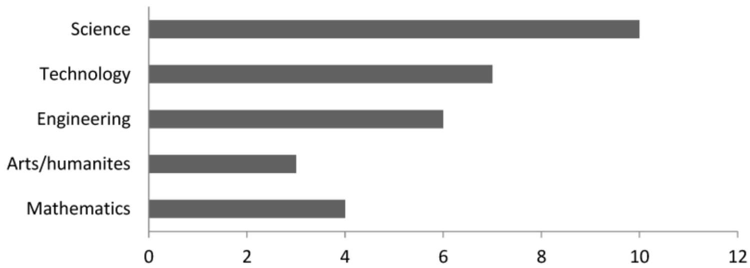

Figure 8. STEAM knowledge areas explicitly addressed in Early Childhood Education for Sustainability (ECEfS).

Following, we present in Figure 9 a horizontal chart bar with the prominent discourses regarding theoretical orientation, children's pictures, and educational perspectives on sustainability.

Most articles are theoretically oriented towards the necessity of connecting children to sustainability (8). This idea underlined experiential learning in sustainability and was applied by some authors as the rationality that justifies bush kinder [24,67] and playscapes [62]. Less frequently addressed, the children's rights orientation encompassed recognising children subjects with the right to construct an opinion and choose to act for sustainability, but, altogether, emphasising that children would have a responsibility for it. For example, Bascopé and Reiss [60] (p. 2) say children should be "encouraged to become problem seekers and solvers in their localities". Alternatively, Campbell and Speldewinde [23] assert that "[e]ven young children can act locally and responsibly in way to change their immediate environment".

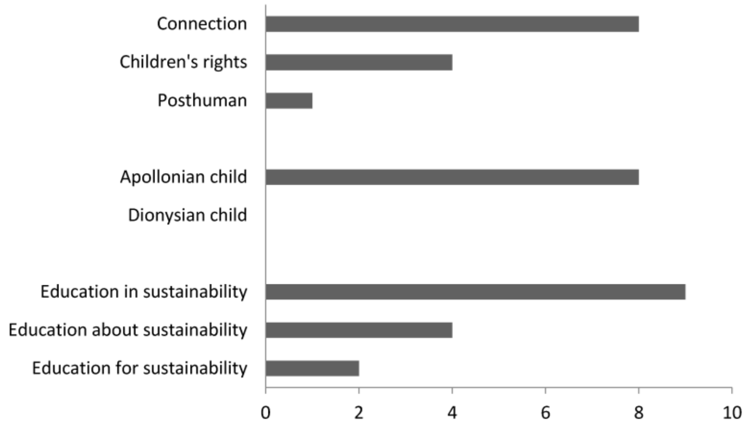

Figure 9. Theoretical orientation, children's nature picture, educational perspectives.

The reviewed articles adopt a picture of children as the Apollonian child. For example, the authors report episodes when children encounter animals and "respectfully" investigate them in bush kinder. Children are not portrayed as a threat that might kill those animals. In this sense, no author centres on the Dionysian child image. However, some facets of this picture appear throughout the texts. For example, Carr and Luken [62] (p. 76) picture the children as Apollonian children. They argue that children's inner desires (assumed as good) should be supported so that "they are more likely to be more sophisticated, diplomatic, and socially mature when adults". Conversely, in another moment, they tilted (even though much less remarkably) to the Dionysian image, saying that "[p]lay leaders encouraged organised games to teach children about following rules and working with teammates. Children were often required to maintain good hygiene and use correct grammar". According to this last view, children would not spontaneously emerge with, e.g., collaborative behaviour that should be supported.

Eventually, most studies remain in the educational perspective of education in sustainability. The authors seem to focus on children's experiences with a sustainable aspect, principally through playful strategies. Spiteri et al. [68] focused on the educational perspective of education about sustainability because they explored children's previous conceptions of nature. Bascopé and Reiss [60] touched on the three educational perspectives, but their study involved a teacher training programme wherein many STEM projects were implemented. Borgerding and Kaya [61] embraced education in sustainability and education about sustainability in the same pedagogical proposal.

In the following paragraphs, we will address some main contributions of the articles addressing their theoretical orientation, children's pictures, and educational perspectives on sustainability.

Aladé et al. [59] explored the impact of eight-week exposure to a counter-stereotypical STEM television program called *Cyberchase*—the protagonists of this show comprise an African-American girl, a Latino-American girl, and an Irish-American boy. They argued that research has shown that children at very early ages already present stereotypical views of STEM professionals [70,71]. For example, boys and girls tend to picture engineers as white men [72,73]. Interestingly, they found no quantifiable difference between interventional and control groups. They justified that the exposition time might not have been sufficient to change their conceptions. In terms of educational perspective, those authors enrolled in education in sustainability regarding the social aspect. In other words, they provided children with an environment where they could experience racial and gender representativeness in STEM. Their central discourse aligned with the idea of children's connection to nature since the authors, based on the cultivation theory, suggest that, through repeated exposure, the children could adopt attitudes consistent with the themes portrayed in the program (we considered nature the social environment). They pictured the pupils primarily as Apollonian children, following the idea that the stereotypes they likely stand for come from the external influence of society, such as the interaction with parents, teachers, books, and regular television shows.

Borgerding and Kaya [61] proposed lessons of a STEAM camp in ECE built around three yarn stories accompanied by visits to nature, play, artistic, and hands-on activities. Students could experience evolutionary and ecological concepts related to three biomes: desert, artic, and deciduous forest. They assigned placards to each child to play with as if they were different organisms. As the story proceeded, a ball was tossed to connect children in a web representing ecosystems. In this sense, we remark that the lessons attended education about sustainability because they learned about ecosystems. For example, the researchers posed questions demanding children to raise their hands if their organism was from the desert/forest/artic or if their organism's colour helped them hide in the show, forest, or sand. STEAM education was remarkably present in the lessons. For instance, they enrolled in a scientific inquiry about ways celery stalks (plants) could be protected from drying out in the summer sun. Children chose some materials such as water, petroleum jelly, and sunscreen. The following day, the children collected data and concluded that petroleum jelly was more effective in protecting them. This experiment approached the cactus characteristic of wax skin that helps them to live in dry and hot deserts. Arts, likewise, had a central role. Children created a large mural with natural features of each biome while discussing necessary evolutionary adaptations, such as lizards having the same colour as the sand.

Moreover, the activities included education in sustainability, showing that the educational perspectives can be combined. Children observed organisms from a walk outside the camp (deciduous forest) and during a visit to a greenhouse. Children's experiences with nature were enriched with a chart to colour and record the observed organisms and discussions related to their experiences and the yarn stories. Regarding this research, we highlight the authors' declared posthuman concerns. They adverted that children as young as two years old expect designed objects to have a function. Eventually, they explain that the "texts were written without reference to intentional teleology and are free of anthropological language". Accordingly, the yarn stories did not present plants and animals through their utilities, as objects to humans, nor from anthropological relationships, such as birds "love" trees. Borgerding and Kaya [61] (p. 86) stated that "children did not want to be assigned plant roles", and the authors had to emphasise how vital plants were to each environment. Finally, we remark that they did not enrol in education for sustainability, such as the need for taking action and changing behaviours to protect the environment and endangered species.

Campbell and Speldewinde explored bush kinder regarding STEM education in ECEfS [23,66] and specific topics such as enabling girls' STEM identities [67] and developing technology and engineering understandings [24]. Since bush kinder aims to connect children with nature through playful activities, those authors repeatedly declare the theoretical orientation of children's connection to nature. They concluded that the bush kinder facilitate STEM because of its rich materials, such as loose parts, that can be moved around, designed, and redesigned. Their studies found evidence of playfulness, problem-solving, design thinking, testing [24], and agency over the scientific language [23]. Additionally, they point out that the natural environment enables girls' STEM identities because it allows playing in an environment with less stereotypical elements, such as toys that retain social gender expectations, compared to traditional and human-altered school ambience.

They prominently picture children as the Apollonian child. They conceive a child as having good intentions and behaviour while exploring the natural world. They highlighted, for example, episodes of environmental care, observing that children would "gently prod" found animals to understand how the animal moves [66] (p. 453). In the vein of children's centrality and the spontaneity of bush kinder, they report that teachers have minimal planning given. In this case, teachers would apply their previous knowledge of STEM and occasionally do some research to support children's learning. The authors say, "[r]ather than spending time in preparing, often there is a need for educators to adopt a place-based approach to their teaching" [66] (p. 447). They stated that at least two disciplines of STEM have to be intentionally emphasised in an activity to be considered STEM. Additionally, they present a cyclical process of STEM in bush kinder, defending that in the "assessment and evaluation" phase, "children evaluate what type of STEM learning has occurred in bush kinder" [66] (p. 452). Notwithstanding, learning skills and knowledge of STEM remained an analysis a posteriori instead of an outcome explicit to students. The authors affirm that "children's learning would be taken from bush kinder into the indoor kindergarten program", but they do not explore this transposition.

Eventually, their proposal lies in the sustainability education category because boys and girls experience activities in nature. However, they do not focus on children reflecting on sustainable issues or taking actions, such as changing behaviour and regarding environmental and gender inequality issues. Those authors claim STEM education would be built as a basis for understanding sustainability issues, such as in the fragment, "[t]he obvious links for EfS with the key disciplines that underpin our understanding of the world (science, technology, engineering, and mathematics) allow students and young children to draw on their understandings in STEM as a basis for acting for sustainability" [66] (p. 3). However, their studies show STEM as an outcome of bush kinder and do not follow the subsequent stage where those understandings could be directly intertwined with sustainability problems. Finally, although they focus the research on STEM education, they demonstrate openness to other knowledge of areas that would comprise STEAM in bush kinder. They stated, "there is the potential for other discipline-based learning domains such as Art, Literacy or Humanities, and their connection to bush kinder STEM teaching and learning, to be explored in future" [66] (p. 459).

5. Discussion and Conclusions

Several international reports warn about the need to change toward a sustainable society [1,3] and summoned education to participate in this endeavour [6,9,13]. We remind that, on the one hand, society has essential and somewhat legitimate demands towards education, such as the eagerness for sustainability [19]. However, on the other hand, we call attention to the fact that education is a teleological practice and, thus, pursues intrinsic objectives [74,75]. From that standpoint, we propose the move from "Education for Sustainability" to "Sustainability for Education", while emphasising the contribution of sustainability to education. In this sense, we particularly remark on sustainable issues providing authentic contexts for developing interdisciplinary educational approaches such as STEM and STEAM education. Accordingly, we enrolled in a systematic review to explore the intersection between ECEfS and STEM/STEAM education.

As a result, on the one hand, we highlight the dearth of research regarding the intersection between EfS and STEM/STEAM in early childhood. We found few studies on the topic (12) that were enrolled in a few countries (7). It reflects that ECE is traditionally overlooked in educational research compared to other levels [16]. The ECE period is usually non-obligatory and has a complex and diverse organisational structure, making it hard to coordinate, such as assuming sustainability is a core topic of interest. ECE is usually voluntary and has limited resources compared to compulsory schooling [17]. Additionally, research practices may encounter particular ethical concerns while involving young children [16]. On the other hand, we point to an augment of interest in the intersection of ECEfS and STEM/STEAM in recent years; 2021 exhibited three studies, which doubled in the following year.

Additionally, we mention that no research addressed the youngest age group, 0 to 2 years old, neither involved their family. Other reviews in EfS arrived at similar results and defended that more researchers should conduct interventional studies encompassing parents [12].

One reviewed study reported null results about exposing children to a counter-stereotypical STEM television series [59]. The remaining authors usually reported good outcomes on the relationship between STEM/STEAM education and ECEfS. We acknowledge the possibility of a bias on the overrepresentation of studies reporting positive impacts, since some researchers and papers are hesitant to publish negative and null findings [15]. At the same time, even though gains for sustainability are legitimate, we suggest stressing educational goals such as learning related to STEM or STEAM education.

The investigation on STEM/STEAM education and ECEfS is centred on the environmental pillar, while social and economic aspects were barely addressed. Previous reviews on EfS have concluded that research on the three pillars of sustainability began in 2016, but environmental studies remain prominent, while the economic aspect is somewhat limited [12]. In this vein, we assert that the lack of theory and practice on sustainability's social and economic pillars implies missing critical educational opportunities. Interventional research on ECEfS should integrate elements from the three pillars of sustainability because they intertwine with each other [3]. Economic aspects, for example, encompass discussions about the environment, such as reducing consumption, reusing, recycling materials, and avoiding waste of resources such as water, energy, and food.

Economic concerns similarly relate to ideas of social inequality and the pursuit of social justice, which is one sustainable challenge of our society [5]. To mention some insights, Borg [76] interviewed preschool children and observed that almost all (94.3%) had some knowledge about poverty. They know about economic inequalities among individuals and countries and may have ideas about addressing those problems. In another study, Borg [77] explained that children's understanding of economics does not necessarily relate to the cash economy. This author operationalised sustainable economic issues with young children using candies. She observed that children mainly demonstrated consumerist behaviour when hypothetically receiving money—they would go shopping or save it for buying something more expensive on a long-term basis. Differently, children exhibited care for others while sharing resources—most of them would share candies because it is kind, just, and so their friends are not sad.

As sustainability encompasses the social pillar, it seems reasonable to incorporate knowledge closely related to understanding societies, such as arts and humanities. Accordingly, STEAM (instead of STEM) would be appropriate because this educational approach considers the fields of arts and humanities in the acronym. However, STEM has a more substantial presence in the literature on ECEfS, and this may reflect on overseeing social issues. This difference implies rethinking EfS, from setting the foundation to developing scientific and technological professionals who could solely provide sustainable solutions. The absence of social and economic pillars signals that EfS is not embracing the complexity of sustainability. Future research on ECEfS should investigate how young children conceive, at an appropriate age level, tensions involved in sustainability, especially from situations related to their daily life at home and school. Accordingly, there is a need for pedagogical strategies that apply STEAM knowledge and skills to foster children's action competence [78]. Accordingly, children investigate sustainable issues (understand them) and develop visions (imagine alternatives, ponder their preferences) to take action and change (engage with them, mind trade-offs, individual and collective sacrifices and the outcomes of actions).

We share with Varela-Losada et al. [11] the judgment that sustainability demands are urgent and that adults are responsible for making today's decisions. At the same time, newcomers should become involved so that future adults may continue the initiatives. However, we shift from "Education for Sustainability" to "Sustainability to Education", highlighting the pedagogical opportunity of authentic context on sustainable issues.

This review indicated that the intersection between STEM/STEAM and ECEfS is currently focused on sustainability's environmental pillar. The literature on this topic usually follows the theoretical orientation connection to nature, adopts the educational perspective of education in sustainability, and pictures children as Apollonian—assuming children are essentially good and emerge with virtuous traits from this contact, such as environmental care. While remaining in education in sustainability, STEM/STEAM knowledge areas were not deepened and explicitly explored with the children. Frequently, the disciplines served as categories of analysis in a posteriori investigation. Conversely, Borgerding and Kaya [61] provided children with experiences of education in sustainability by visiting a forest around the STEAM camp and a greenhouse, combined with an intense phase of education about sustainability where children learned about scientific concepts of ecology and biomes.

Worryingly, the educational perspective of education for sustainability could be identified only in research about teacher training programmes. We claim that more studies should focus on children's awareness and engagement with actions on sustainable issues. Future research should focus on children taking (age-appropriate) action on sustainability, such as reducing consumption and reutilising and recycling products. Accordingly, we evoke the concept of action competence proposed by Jensen [78]. This concept criticises health and environmental education from a moralistic pedagogy, suggesting that just knowledge is not enough. People must undergo deep reflection to make effective transformation occur. In this sense, simply demanding children to have sustainable behaviour is not enough. They must feel connected to it somehow and understand the rationalities behind assuming and engaging with different behaviours [78].

STEAM in ECEfS requires intentionality—the child-led transdisciplinary (no distinction between knowledge areas) experience has to be balanced with interdisciplinary interventions (explicit knowledge areas and their intersections) representing educational contribution. Similarly, we suggest future research addressing particular STEAM disciplines, such as science or engineering education, in the context of ECEfS. There might be exciting studies that enrol interdisciplinary teaching with those knowledge areas but are not framed on STEM/STEAM education.

Explicating knowledge areas and their intersections require teachers' preparedness to be more than just "supporters" since they have something to add to the transdisciplinary experience. This review found only three articles on teacher training in STEM/STEAM and ECEfS. Researchers have warned that teachers are not sufficiently trained to teach sustainability [79]. Currently, there are some efforts intending to reorient teacher training for sustainability [80]. Additionally, teacher training in STEAM education has concluded that this educational approach is complex to enrol in and requires appropriate planning [51].

This study enlightens essential theoretical orientations, educational perspectives, and pictures of children's nature that might help future practice and research in ECEfS. We suggest more research on the intersection of STEAM and EfS, such as thematic reviews, regarding specific settings of ECE, such as the strong connection with playful learning [45,62]. Subsequent investigations should distend from the Apollonian child picture and the belief that children can emerge long-term sustainable concerns just by education in sustainability. The theoretical orientation of connection to nature could instead reinforce the idea that education for sustainability purely might be insufficient if children are disconnected and disengaged from sustainable issues. In sum, we claim that children should undergo education in, about, and for sustainability to achieve the capital letter Education for Sustainability. Consequently, future research should expand educational practices to incorporate experience, knowledge, skills, awareness, and action involving sustainable issues while considering integrated environmental, social, and economic pillars.

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ARTICLE 4

STEAM education and playful learning at all educational levels

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LA EDUCACIÓN STEAM Y EL APRENDIZAJE LÚDICO EN TODOS LOS NIVELES EDUCATIVOS

STEAM EDUCATION AND PLAYFUL LEARNING AT ALL EDUCATIONAL LEVELS

Jefferson Rodrigues-Silva
Mestre em Engenharia Mecânica pela Universidade Federal de São João del-Rei (São João del-Rei/Brasil).
Doutorando em Educação pela Universidade de Girona (Girona/Espanha).
Professor no Instituto Federal de Minas Gerais (Arcos/Brasil).
E-mail: jeffe.rodri@gmail.com
Orcid: https://orcid.org/0000-0002-8334-2107

Ángel Alsina
Doutor em Psicologia pela Universidade Autônoma de Barcelona (Barcelona/Espanha).
Professor de didática da matemática na Universidade de Girona (Girona/Espanha).
E-mail: angel.alsina@udg.edu
Orcid: https://orcid.org/0000-0001-8506-1838

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RESUMEN

Se presenta una revisión narrativa de la literatura en las bases de datos *Web of Science* y *Scopus* cuyo objetivo es explorar la relación entre la educación STEAM (acrónimo en inglés de la interdisciplinaridad entre Ciencias, Tecnología, Ingeniería, Artes/humanidades y Matemáticas) y el aprendizaje lúdico. La revisión se ha realizado en cuatro fases: 1) elementos de búsqueda y lógica Booleana, 2) fuentes de información, 3) criterios de elegibilidad y 4) proceso de recogida y análisis de datos. A partir de los artículos revisados, en primer lugar, se presenta brevemente la evolución histórica y las definiciones de ambos enfoques y, seguidamente, se exploran evidencias de experiencias de educación STEAM a partir de metodologías de enseñanza basadas en el aprendizaje lúdico: el juego libre, el juego guiado, el juego formal y la gamificación. En segundo lugar, se analiza la intersección entre ambos enfoques en torno a la creatividad y se destacan implicaciones para el desarrollo profesional del profesorado. Se concluye que los vínculos entre la educación STEAM y el aprendizaje lúdico son cognitivamente potentes y factibles en todos los niveles educativos; sin embargo, aportan una complejidad al planteamiento didáctico, lo cual requiere conocimientos que el profesorado no tiene y eso puede generar cierta resistencia y conflictos cognitivos. Finalmente, se ha identificado la necesidad de una comprensión más amplia del aprendizaje lúdico, de más investigaciones y de una formación apropiada al profesorado sobre el *networking* STEAM-lúdico.

Palabras clave: Educación STEAM. Aprendizaje lúdico. *Networking* entre enfoques educativos. Desarrollo profesional del profesorado. Revisión narrativa de la literatura.

ABSTRACT

A narrative review of the literature in the *Web of Science* and *Scopus* databases is presented. Its objective is to explore the relationship between STEAM education (an acronym in English for interdisciplinarity between Sciences, Technology, Engineering, Arts/Humanities and Mathematics) and playful learning. The review has been structured in four phases: 1) search elements and Boolean logic, 2) information sources, 3) eligibility criteria, and 4) data collection and analysis processes. From the reviewed articles, first, we briefly present the historical evolution and the definitions of these two approaches, and then evidence of experiences on STEAM education which were conducted through playful-based teaching methodologies: free play, guided play, formal game and gamification. Second, we analysed the intersection between both approaches regarding creativity and highlighted implications for teacher professional development. We concluded that the connections between STEAM education and playful learning are cognitively powerful and feasible at all educational levels; however, they add complexity to the didactic design, which requires knowledge teachers may not have. That can generate some resistance and cognitive conflicts. Finally, there is a need for a broader understanding of playful learning, more research, and appropriate teacher training on STEAM-playful networking.

Keywords: STEAM education. Playful learning. Networking between educational approaches. Teacher professional development. Narrative literature review.

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1 INTRODUCCIÓN

Hay divergencias entre los investigadores sobre la caracterización del aprendizaje lúdico (MITTON; MURRAY-ORR, 2022). Sin embargo, existe al menos un aspecto en el que parecen estar de acuerdo, el concepto lúdico es difícil de definir (MITTON; MURRAY-ORR, 2022; SCHLESINGER *et al.*, 2020; ZOSH *et al.*, 2018). Quizás, por este motivo, lo lúdico suele trabajarse de manera rígida, vacía y sin matices (ZOSH *et al.*, 2018).

En la investigación educativa, el aprendizaje lúdico tiene reconocida importancia, principalmente en las primeras edades (MITTON; MURRAY-ORR, 2022; OECD, 2019). En el juego libre, por ejemplo, una actividad donde los niños crean un mundo de aventuras imaginarias, se observa el desarrollo de procesos de observación, comunicación y experimentación (BAGIATI; EVANGELOU, 2016). Efectivamente, diversos estudios muestran beneficios del juego en el dominio afectivo del alumnado, mejorando su motivación y consecuentemente el aprendizaje de contenidos y el desarrollo de habilidades (ESPIGARES-GÁMEZ; FERNÁNDEZ-OLIVERAS; OLIVERAS CONTRERAS, 2020; SOUZA; RIOS, 2010). Las actividades lúdicas son utilizadas, por ejemplo, como intervenciones terapéuticas para niños que presentan desatención, agresividad, etc., mientras están en espera para recibir atención psicológica (LEVANDOWSKI, 2016).

Recientemente, países como Estados Unidos y Corea han incorporado abordajes interdisciplinares (KIM; BOLGER, 2017). En el caso de España, el currículo para la educación primaria hace referencia explícita a la integración de disciplinas a través del enfoque STEM (por el acrónimo en inglés de Ciencias, Tecnología, Ingeniería y Matemáticas) mediante competencias que deben ser desarrolladas en estos niveles. Este país también fomenta lo lúdico, como cuando se describe, para el primer ciclo de primaria, la competencia de "participar en actividades lúdico-recreativas de forma segura en los entornos natural y urbano y en contextos terrestres o acuáticos [...]" (MEFP, 2022, p. 24445).

Paralelamente, crece el número de investigaciones educativas que apuestan por la educación integrada STEAM (acrónimo del inglés de Ciencias, Tecnología, Ingeniería, Artes/humanidades y Matemáticas) (MARÍN-MARÍN *et al.*, 2021). Este abordaje educacional se justifica principalmente por el argumento de que los problemas del mundo contemporáneo son complejos, lo que demanda, por lo tanto, soluciones creativas que sólo son posibles a partir del uso holístico de conocimientos y habilidades de diferentes áreas.

Con esta intención, la literatura generalmente caracteriza la educación STEAM con visiones de la enseñanza contemporáneamente consideradas óptimas desde las ciencias cognitivas: aprendizaje activo, auténtico, significativo y colaborativo (ZOSH *et al.*, 2018). Dentro de las metodologías practicadas en STEAM, algunas son entendidas como lúdicas, como el teatro (SMYRNAIOU *et al.*, 2017), el juego

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(ESPIGARES-GÁMEZ; FERNÁNDEZ-OLIVERAS; OLIVERAS CONTRERAS, 2020) o la gamificación (LÓPEZ; RODRIGUES-SILVA; ALSINA, 2021).

Considerando, pues, la relación entre STEAM y el aprendizaje lúdico, se puede hablar de *networking* de teorías o enfoques educativos para el diálogo, conjetura, comparación y síntesis de estos enfoques educativos (RODRÍGUEZ-NIETO; ALSINA, 2022). Uno de las ventajas del *networking* es que contribuye a que un enfoque educativo sea entendible desde la perspectiva del otro (RODRÍGUEZ-NIETO; FONT; RODRÍGUEZ-VÁSQUEZ, 2022). Desde este prisma, pese a la gran diversidad de metodologías lúdicas aplicadas a la educación STEAM, existe todavía una escasa profundización en la articulación de estos dos enfoques. Eso nos genera el siguiente interrogante: ¿Cómo se vinculan el aprendizaje lúdico y la Educación STEAM en las prácticas de enseñanza?

Con base en los antecedentes descritos y considerando esta pregunta, el objetivo de este estudio es explorar las relaciones entre el aprendizaje lúdico y la educación interdisciplinar STEAM a partir de una revisión narrativa de la literatura (GREEN; JOHNSON; ADAMS, 2006), para ampliar el *networking* entre ambos enfoques educativos y obtener implicaciones para el desarrollo profesional del profesorado.

2 METODOLOGÍA

Con base en el objetivo planteado, se ha desarrollado una revisión narrativa, la cual permite reportar una visión amplia sobre un determinado tema de forma coherente y condensada. Adicionalmente, es una forma de promoción del diálogo sobre tópicos que posean divergencias y controversias (GREEN; JOHNSON; ADAMS, 2006). Asimismo, esta metodología se muestra apropiada para una investigación que se proyecta a hacer una lectura crítica del *networking* de dos enfoques educativos. Considerando estos planteamientos, se ha estructurado la revisión en cuatro fases: 1) elementos de búsqueda y lógica Booleana, 2) fuentes de información, 3) criterios de elegibilidad y 4) proceso de recogida y análisis de datos.

Elementos de búsqueda y lógica Booleana: a partir del objetivo de explorar el vínculo entre el aprendizaje lúdico y la Educación STEAM, primero se ha identificado que las expresiones *lúdico* y *STEAM* son elementos centrales de la investigación. Seguidamente, se ha establecido la lógica Booleana PLAY* or LUDIC* and STEAM. Sobre la fórmula, se aclara que las formas cortas *play* y *ludic* contemplan una lista de palabras de interés de la misma familia: *play, playful, playfulnes playfull – ludic, ludicity*.

Fuentes de información: se han determinado las bases de datos de *Web of Science* (Clarivate) y *Scopus* (Elsevier) como las fuentes para la búsqueda de documentos. Estas dos fuentes de consulta han sido seleccionadas por su elevado prestigio en la investigación educativa.

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Criterios de elegibilidad: tal como se indica en la Tabla 1, se han incluido solo artículos que han sido evaluados por pares porque el rigor de estas revisiones indica mejor calidad de la investigación. En relación al periodo de publicación, se han considerado artículos publicados a partir de 2007, que fue el año de creación del acrónimo STEAM (PERIGNAT; KATZ-BUONINCONTRO, 2019). Finalmente, se han incluido documentos publicados en inglés, por su alto alcance en la ciencia educativa, así como también el español y el portugués para aprovechar el conocimiento de los autores y tener una mayor amplitud del estudio. Los criterios de exclusión han sido básicamente los contrarios de los de inclusión.

Tabla 1 – Criterios de elegibilidad

Criterio	Inclusión	Exclusión
Tipo de documento	Artículos evaluado por pares	Otros
Periodo de publicación	A partir de 2007	Anterior a 2007
Idioma	Inglés, español y portugués	otros

Fuente: los propios autores

Proceso de recogida y análisis de datos: la investigación se ha iniciado a partir de una exploración preliminar, con el doble propósito de actualizar los conocimientos de los autores y refinar palabras de búsqueda (GREEN; JOHNSON; ADAMS, 2006). En esta primera parte, por ejemplo, los autores han constatado que la búsqueda de artículos en *Web of Science* con la lógica booleana inicialmente establecida era muy restrictiva. Esta plataforma indicaba 23 artículos pero en 21 de ellos la palabra *play* tenía acepciones que no correspondían al aprendizaje lúdico, como por ejemplo en la expresión *play a role*, que significa desarrollar un papel determinado.

Dado la escasez en la literatura, se ha optado por explorar el aprendizaje lúdico a partir de algunas de las principales metodologías de enseñanza enmarcadas en este enfoque: el juego libre, el juego guiado, el juego formal y la gamificación. De esta forma, se han hecho nuevas búsquedas en las bases de datos usando directamente el nombre de cada metodología de enseñanza lúdica y STEAM. Nuevamente, se han empleado los criterios de elegibilidad previamente establecidos y, adicionalmente, se han añadido los criterios de incluir trabajos empíricos que involucrasen estudiantes. Mediante esta estrategia ha sido posible identificar artículos con evidencias empíricas del aprendizaje lúdico enmarcadas en el contexto de desarrollo de la educación STEAM.

Además, desde el análisis iterativo y comparativo de los documentos, han emergido dos temas que, posteriormente, se han profundizado: la creatividad y las implicaciones para el desarrollo profesional del

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profesorado. Esta ampliación es coherente con la revisión narrativa, que se dedica a profundizar sobre tópicos aún poco explorados o cuya sistematización no sería posible (GREEN; JOHNSON; ADAMS, 2006).

3 RESULTADOS

Con base en la revisión narrativa realizada, se sigue el siguiente proceso de exposición de los datos obtenidos: 1) se describen los datos correspondientes al aprendizaje lúdico y la educación STEAM separadamente, explorando brevemente la evolución histórica y las definiciones de cada enfoque; 2) se analizan experiencias reportadas en la literatura en torno a los vínculos entre ambos enfoques; 3) se indaga en torno a la intersección de estos dos enfoques educativos a partir del concepto de creatividad; y 4) se exploran implicaciones para el desarrollo profesional del profesorado.

3.1 EL APRENDIZAJE LÚDICO

El comportamiento lúdico se ha identificado en un gran número de mamíferos y aves. En este sentido, se argumenta que lo lúdico representa un método evolutivo de adaptación a nuevos entornos (BONDI; BONDI, 2021). Huizinga (1938), sin embargo, afirma que lo lúdico sería la esencia misma de los seres humanos.

En efecto, la infancia parece que se asocia a lo lúdico. Respecto a esto, se observa que existe una preocupación, que es compartida a nivel mundial, de garantía del derecho a jugar de los niños, tal como se observa en la Convención sobre los Derechos del Niño (NACIONES UNIDAS, 1989). En España, por ejemplo, el currículo menciona lo lúdico en los tres ciclos de la educación primaria (MEFP, 2022). Para el tercer ciclo, por ejemplo, se describe que los niños deben ser capaces de:

> Aplicar principios básicos de toma de decisiones en situaciones lúdicas, juegos modificados y actividades deportivas a partir de la anticipación, ajustándolos a las demandas derivadas de los objetivos motores y a la lógica interna de situaciones individuales, de cooperación, de oposición y de colaboración-oposición, en contextos reales o simulados de actuación, reflexionando sobre las soluciones obtenidas. (MEFP, 2022, p. 24449).

Cabe señalar que, en el caso concreto del currículo español, focaliza bastante lo lúdico desde la perspectiva del desarrollo motriz. Pero aun así, en este mismo fragmento del currículo, se observan pistas para el desarrollo de habilidades cognitivas, como la imaginación para contextos simulados de actuación, y también el desarrollo del dominio afectivo, como en las situaciones de colaboración y oposición. De ello se desprende que el aprendizaje lúdico ocupa un lugar relevante en la infancia.

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Desde una perspectiva más teórica, según Vygotsky (1980), los niños tienden a satisfacer sus deseos inmediatamente. Cuando los deseos no pueden ser satisfechos, los infantes resuelven esta tensión involucrándose en un mundo ilusorio e imaginario en el que estos deseos son realizados, un mundo imaginado que es lúdico.

Los adultos también imaginan mundos diferentes de su realidad. En la Utopía de Thomas More (1949), por ejemplo, lo lúdico tenía un lugar reservado: los ciudadanos tenían seis horas obligatorias de trabajo, mientras que el tiempo restante del día sería dedicado a ejercicios propios tales como lectura, conversación, música y juegos, excepto los juegos de apuestas (que estaban prohibidos).

En nuestra sociedad, sin embargo, en la vida adulta se incorporan obligaciones que, requiriendo responsabilidad para ser cumplidas, parecen tomar el espacio de cualquier tipo de actividad de ocio. De hecho, Schlesinger *et al*. (2020) aseveran que, en occidente, lo lúdico está desapareciendo incluso de la vida de los niños (SCHLESINGER *et al*., 2020). Ellos indagan, por ejemplo, sobre la prisa de iniciar la enseñanza formal para evitar "pérdida de tiempo" de los más pequeños. Todo este panorama requiere indagar acerca del papel de lo lúdico en la educación de los niños y los adultos. Pero, ¿qué es "lúdico"?

"Lúdico" es un tipo de concepto cuyo significado parece muy claro hasta el momento en que se decide realmente pensar en ello. Es como un substrato evidente de algunas actividades en que *el mientras* gana énfasis sobre *el fin*, pues como se está divirtiendo, no se quiere que la experiencia, sea cual sea, termine. Algunos investigadores, por ejemplo, consideran actividades lúdicas únicamente las que son fruto de una acción voluntaria (iniciadas por los propios niños), autogestionadas (sin la interferencia de un adulto) y con fines en sí mismas (sin objetivos extrínsecos) (ZOSH *et al*., 2018).

En este marco, se encontraría el juego libre, donde los niños se lanzan voluntariamente a un mundo de imaginación. No obstante, esta definición deja fuera del concepto de lúdico cualquier actividad por el simple hecho de haber sido propuesta por un adulto o por tener un objetivo extrínseco. Entonces, metodologías de enseñanza tales como el Aprendizaje Basado en el Juego, bajo esta concepción más restrictiva, ya no podría ser considerada lúdica, ya que suele ser propuesta por el maestro y tiene un objetivo extrínseco, el del aprendizaje.

Tal concepción conduciría, además, a pensar lo lúdico dedicado a los niños de menos edad, como un privilegio que en un determinado momento se les acaba. De este modo, ¿se reserva a los adultos una vida sin alegría, donde lo lúdico es binariamente sustituido por el trabajo y por la responsabilidad?

De hecho, las investigaciones sobre el aprendizaje lúdico están mucho más presentes en la educación infantil (MITTON; MURRAY-ORR, 2022; OECD, 2019), mientras que es muy poco considerada en otras etapas educativas, como en la educación superior (CHATTERJI *et al*., 2021). Todo esto indica claramente

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que, en específico para el área de la educación, se necesita una comprensión más amplia y profunda de lo lúdico (WEISBERG; HIRSH-PASEK; GOLINKOFF, 2013). Se requiere que este constructo tenga matices que lo diferencien en función de la edad de los individuos a lo largo del continuum de los niveles educativos (MITTON; MURRAY-ORR, 2022; OECD, 2019).

Ya desde el marco de ampliación del concepto de lo lúdico, Caillois (1958) identifica un elemento espontáneo de búsqueda de placer y diversión (*paidia*), pero también, la satisfacción del esfuerzo de ganar a través de la presencia de restricciones, límites, obstáculos, enigmas y reglas (*ludus*).

Zosh *et al.* (2018), proponen que lo lúdico sea entendido como un espectro que va desde el juego libre (iniciado y dirigido por los niños y sin objetivos extrínsecos) hasta llegar a la instrucción lúdica (iniciada y dirigida por un adulto y con objetivos extrínsecos), como se muestra en el Figura 1.

Figura 1 – Lo lúdico conceptualizado como un espectro

Fuente: Elaboración propia

A lo largo de este espectro, las actividades lúdicas se vuelven más formales y estructuradas a medida que las personas tienen más edad (MITTON; MURRAY-ORR, 2022; OECD, 2019; ZOSH *et al.*, 2018). Al respecto, sobre el ocio de los adolescentes, por ejemplo, diversas investigaciones apuntan que las actividades estructuradas y supervisadas por adultos están relacionadas con mayores beneficios académicos, psicológicos y de comportamiento, en comparación con las actividades no estructuradas (OECD, 2019).

Dentro de este espectro, por lo tanto, se conciben diversas actividades lúdicas. Además de las que están listadas, los puntos suspensivos indican que otras actividades pueden ser consideradas también en contextos lúdicos, como el teatro, la danza, las competiciones deportivas, etc.

Muchas de las actividades lúdicas indicadas pueden ser aplicadas a metodologías de enseñanza en la educación STEAM. A continuación, pues, se revisa el enfoque educativo STEAM y se indaga en torno a

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la convergencia de estas diversas metodologías y la educación STEAM: el juego libre, el juego guiado, el juego formal y la gamificación.

3.2 LA EDUCACIÓN INTEGRADA STEM Y STEAM

La historia del movimiento STEM, acrónimo que se refiriere a la integración de las áreas de Ciencia, Tecnología, Ingeniería y Matemáticas (CATTERALL, 2017) se relaciona íntimamente con la historia de la educación STEAM. Por este motivo, se empieza este tópico por el origen de STEM.

Algunos autores asocian el inicio del movimiento STEM al lanzamiento del satélite *Sputnik* por parte de la Unión Soviética en 1957: el primer objeto creado por el hombre para orbitar un cuerpo celeste, nuestra Tierra. Este episodio ocurrió dentro de un escenario mundial polarizado por la Guerra Fría. Esta hazaña generó respuestas de los Estados Unidos; entre ellas, medidas urgentes hacia la formación de profesionales que pudiesen lograr la superioridad tecnológica y económica de este país (ZOLLMAN, 2012).

Por otro lado, Chesky y Wolfmeyer (2015) resaltan que las iniciativas hacia la centralización de la educación en torno a algunas áreas consideradas más científicas y tecnológicas es anterior al lanzamiento del satélite: por ejemplo, en las declaraciones oficiales del ingeniero Vannevar Bush, quien escribió al presidente Eisenhower en 1940 pidiendo "estructuras educativas para preparar a los futuros científicos de la nación" (p. 5).

Se puede determinar precisamente cuando y donde nace STEM como un acrónimo: fue formalizado en la década de 1990 por la *National Science Foundation* (NSF) en los Estados Unidos. Por otro lado, STEM como una estrategia política de enfoque de las cuatro áreas del conocimiento, es algo más difuso y quizás remonte a la revolución industrial o simplemente no esté asociado a una región y fecha específica. De hecho, este movimiento estaría relacionado con la creación de la NSF misma (Chesky y Wolfmeyer 2015), lo que nos conduce a un giro histórico al pensar que el movimiento STEM precede la NSF, institución que luego formalizaría el acrónimo como STEM (CATTERALL, 2017).

Posteriormente, STEM fue evolucionando hacia un abordaje educacional. Las cuatro áreas mencionadas de la sigla pasan a ser articuladas bajo la propuesta de la interdisciplinariedad para componer un cuerpo STEM. Este abordaje se impregna, entonces, de pensamientos filosóficos, como por ejemplo las aportaciones de Dewey sobre la relación de aprendizaje y experiencia (MERCAU, 2022); y también de algunos consensos contemporáneos de las ciencias cognitivas sobre condiciones óptimas para el aprendizaje: un aprendizaje socialmente interactivo, contextualizado (QUIGLEY; HERRO, 2019) y significativo (aplicado a conocimientos previos y transferidos al mondo exterior) (SCHLESINGER *et al.*, 2020), con participación activa del alumno, considerando su dominio afectivo (curiosidad, involucramiento

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y realización) y el desarrollo de la metacognición (capacidad de reflexionar sobre el propio pensamiento y la forma en que se aprende) (ZOLLMAN, 2012).

A medida que STEM se consolida en la educación, las áreas excluidas del acrónimo sienten el impacto, sobre todo por la política del "*pipe line*", una fuente de recursos financieros que privilegian las áreas STEM. En contraposición, en el año de 2007, surgió STEAM, agregándole A de Artes al acrónimo STEM, como una nueva pedagogía en una discusión de la *Americans for the Arts-National Policy Roundtable*: "para ayudar a contrarrestar el mayor enfoque en las materias STEM y la disminución de la educación artística en los EE.UU. durante la última década" (PERIGNAT; KATZ-BUONINCONTRO, 2019, p. 32). Seguidamente, los investigadores pasaron a defender que la "A" podría ampliar más el acrónimo, significando Artes/humanidades.

STEAM comparte objetivos con STEM, ambos se apoyan en la necesidad de preparar a las personas para un mundo en constante cambio (PERIGNAT; KATZ-BUONINCONTRO, 2019), donde los problemas complejos necesitan soluciones creativas que solo son posibles a través del acercamiento interdisciplinar. A un nivel macro, promueve el desarrollo en tecnología e ingeniería para la competitividad económica nacional, pero también se incorporan preocupaciones como la sostenibilidad (HSIAO; SU, 2021; VICENTE; LLINARES; SÁNCHEZ, 2020) y la equidad de género (CABELLO *et al.*, 2021; TAN *et al.*, 2020). En el nivel micro, los objetivos para el individuo incluyen habilidades personales como el desarrollo de la creatividad (MARÍN-MARÍN *et al.*, 2021), la alfabetización para el pensamiento crítico (ZHARYLGASSOVA *et al.*, 2021) y la autonomía (KUMPULAINEN; KAJAMAA, 2020).

Aguilera y Ortiz-Revilla (2021) evidenciaron que la definición de STEAM sigue siendo un debate abierto. Desde nuestro punto de vista, a partir del análisis contrastado de múltiples definiciones de la literatura, STEAM, en sus aspectos centrales, es un abordaje educativo, que en su conjunto de prácticas, promueve el aprendizaje interdisciplinar entre las áreas del conocimiento de Ciencias, Tecnología, Ingeniería, Artes/Humanidades y Matemáticas. STEAM es aplicable sobre el continuum de niveles educativos y por múltiples metodologías de enseñanza en el sentido de promover el aprendizaje activo, auténtico, significativo, colaborativo del alumnado, etc. Además, tal como se plantea en esta revisión narrativa, el enfoque educativo STEAM también es abordado desde lo lúdico.

Desde el punto de vista de la política educativa, el nuevo currículo español, por ejemplo, cita explícitamente STEM y lista competencias relativas a las áreas del acrónimo:

> La competencia matemática permite desarrollar y aplicar la perspectiva y el razonamiento matemáticos con el fin de resolver diversos problemas en diferentes contextos. La competencia en ciencia conlleva la comprensión y explicación del entorno natural y social, utilizando un conjunto de conocimientos y metodologías, incluidas la observación

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> y la experimentación, con el fin de plantear preguntas y extraer conclusiones basadas en pruebas para poder interpretar y transformar el mundo natural y el contexto social. La competencia en tecnología e ingeniería comprende la aplicación de los conocimientos y metodologías propios de las ciencias para transformar nuestra sociedad de acuerdo con las necesidades o deseos de las personas en un marco de seguridad, responsabilidad y sostenibilidad. (MEFP, 2022, p. 24445).

Aun considerando que, para algunos autores, la presencia de las competencias en el currículo es discutible, ya que "confunden hacer y comprender y cuya plasticidad genera una copiosa literatura sobre su definición y alcance" (AZCÁRRAGA, 2022, p. 111-112), la explicitación del acrónimo STEM en el currículo es un gran paso de España hacia la implementación de un enfoque educativo integrado en sus escuelas. Además, dada la relación estrecha entre STEM y STEAM, se espera que STEAM también se vea impulsado en el país. Esta implementación, sin embargo, dependerá de factores como la gestión escolar, la disponibilidad de recursos y la formación apropiada del profesorado. Sobre este aspecto, se puede extender esta consideración tanto para STEAM como para el aprendizaje lúdico.

3.3. STEAM Y EL APRENDIZAJE LÚDICO EVIDENCIADOS EN LA PRÁCTICA

A continuación, se describen una serie de evidencias empíricas en torno a las conexiones entre STEAM y el aprendizaje el lúdico. Se inicia por el juego libre, pasando por el juego guiado, el juego formal, hasta la gamificación. Sobre todo, se presentan experiencias de estas metodologías de enseñanza aplicadas a los diversos niveles educativos y edades.

3.3.1 Juego libre

El juego libre se refiere a actividades de simulacro e imaginación entre los niños. Estas actividades reúnen algunas características: son de libre elección, autoguiadas, voluntarias y altamente flexibles (MITTON; MURRAY-ORR, 2022). Uhlenberg y Geiken (2021) observaron que los niños pequeños (0-3 años), cuando se les proporciona un ambiente con materiales manipulativos, presentan acciones espaciales durante los juegos libres, como acumulación, distribución, colección y correspondencia uno a uno. Los autores argumentan que estos temas están estrechamente relacionados con todos los componentes de STEM, en particular las matemáticas.

Bagiati y Evangelou (2016) argumentan que los niños en edad preescolar pueden aprender matemáticas, lenguas y ciencias jugando libremente con bloques. Según ellos, este tipo de actividad permite que los niños argumenten diversos conceptos, por ejemplo, doble, unidad, tamaño, equilibrio, peso, etc. Estos autores concluyeron que los niños poseen comportamientos innatos precursores del pensamiento de ingeniería y que estos emergen durante el juego libre con bloques. Por ejemplo, los niños

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identifican necesidades y problemas, establecen objetivos, testan soluciones, colaboran y prestan ideas entre sí.

Por otro lado, Fleer (2021) constató que en un juego libre de construcción de puentes, las niñas tendían a no quedarse en el área de ingeniería. La autora alertó que los niños fueron quienes mayoritariamente se situaban en esta área, lo que podría impactar negativamente en las chicas por proyectarse en el futuro como ingenieras u otras profesiones STEM.

3.3.2 Juego guiado

De manera similar al juego libre, en el juego guiado los niños también participan de actividades de simulacro e imaginación. Ellos continúan siendo participantes activos que imaginan y deciden el rumbo de la historia imaginada en el juego. A diferencia, en el juego guiado hay un adulto quien propone un contexto inicial, la configuración del proceso educativo, los objetivos de aprendizaje y, posteriormente, monitora la progresión del estudiante (MITTON; MURRAY-ORR, 2022). En este marco, por ejemplo, Stephenson *et al.* (2021) propusieron una actividad de imaginación que involucró a los niños a convertirse en ingenieros para construir una máquina voladora para ayudar a un dragón, que al ser demasiado grande tenía dificultad de unirse a sus amigos para un picnic espacial. A diferencia del juego libre, en este caso los profesores daban apoyo a los niños, actuando para evitar micro agresiones de género. Las autoras concluyeron que fue posible crear condiciones motivadoras que conduzcan al surgimiento del pensamiento STEM y ofrecer un espacio positivo, atractivo y seguro para las niñas en una etapa crucial en la formación de su identidad personal.

También con cierta participación docente, Reuter y Leuchter (2021) propusieron un juego guiado apostando en la capacidad de los niños en edad preescolar de entender la transmisión de movimiento. En esta propuesta, niños de 5 a 6 años manipularon manivelas, engranajes de diferentes tamaños y conectores. Los niños podían elegir cartas que mostraban diferentes configuraciones de ensamblaje. El profesor hacía preguntas sobre las direcciones y velocidades de los componentes pero no anticipaba soluciones. Cuando los niños llegaban a ideas correctas, entonces se reforzaban las conclusiones alcanzadas. Pre y posttest indicaron que el juego guiado posibilitó el aprendizaje conceptual de engranajes en estos alumnos.

3.3.3 Juego formal

Los juegos formales son definidos de distintas maneras. Para Stenros (2017), los juegos formales poseen un sistema de funcionamiento basado en reglas pactadas y bien definidas. Espigares-Gámez *et al.* (2020) diseñaron una propuesta didáctica centrada en los juegos tradicionales de Jamaica y la

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implementaron en la educación infantil y primaria en España. Concluyeron que los juegos proveen un ambiente intercultural con potencial didáctico para el aprendizaje científico-matemático contextualizado, también de desarrollo de la sensibilidad musical, de la psicomotricidad y de la orientación espacial. Fernández-Oliveras *et al.* (2021) también apostaron por un acercamiento intercultural de los juegos (etnomatemático). En esto caso, niños de educación primaria construyeron juegos de tablero originarios de las culturas Guanche (Islas Canarias), Nazarí (España) y Vikingo (Escandinavia). A partir del juego de los niños, las autoras observaron contenidos fundamentales del currículo de educación primaria: clasificar, organizar, medir y cuantificar ítems, así como formular hipótesis, sacar conclusiones, ubicarse en el espacio y diseñar estrategias.

La literatura incluye también relatos de algunos juegos educativos en la educación secundaria. Aurava y Meriläinen (2022) organizaron encuentros de diseño colaborativo de juegos digitales para estudiantes de esta etapa educativa. Los adolescentes reportaron que la actividad fue una oportunidad de aliviar el stress del aprendizaje de conocimientos STEAM, sobre todo de tecnología de la información, y también habilidades "blandas", como la cooperación. Al final del evento, ellos se sintieron motivados por participar en proyectos colaborativos de creación.

Por supuesto, los adultos con más de 60 años también se benefician con juegos con fines educativos. Esta fue la conclusión de un estudio realizado por Seah *et al.* (2018). Estos autores examinaron una experiencia de bingo digital educativo integrado con contenido sobre nutrición y salud. Los resultados de la investigación evidenciaron mayor conocimiento sobre estos tópicos, pero también conexión social y actitudes positivas hacia los juegos digitales.

3.3.4 Gamificación

La gamificación parece dar un paso más allá, llevando elementos de juego a contextos que no son juegos. A partir de esta estrategia se presentan objetivos explícitos del contexto, por ejemplo objetivos educativos, mientras se proporciona una experiencia lúdica (LÓPEZ; RODRIGUES-SILVA; ALSINA, 2021).

El uso de la gamifición es observado en los diferentes niveles educativos. Ricoy y Sánchez-Martínez (2022), por ejemplo, examinaron el impacto de un programa en educación primaria para la conciencia ecológica y la alfabetización digital utilizando herramientas de gamificación.

Archilla Segade y Cruz (2021) diseñaron e implementaron actividades gamificadas en el aula de música de educación secundaria. Estas eran del tipo *escape room* y preguntas para dispositivos móviles. Además, aplicaron medallas, un panel de clasificación y recompensas como elementos de motivación. Los autores observaron un alto grado de satisfacción y motivación de los alumnos, lo que invita a un aprendizaje de los contenidos de música asociados a tecnología de la información.

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En la educación superior, Gamarra *et al*. (2022) propusieron la gamificación basada en recompensas, competición, trabajo en equipo y retos a estudiantes de ingeniería electrónica e ingeniería de sistemas. Observaron que la propuesta tuvo una grande aceptación y participación de los estudiantes. Además, la estrategia les motivo a involucrarse en las actividades. Boytchev y Boytcheva (2020) reportaron la evaluación gamificada en cursos STEAM para la educación superior a través de un software especialmente diseñado. Según ellos, los estudiantes demostraron rendimiento y motivación positivos.

Una de las mayores críticas hacia la gamificación sería que su impacto motivador podría ser resultado del mero efecto novedad. En este sentido, Rodrigues *et al*. (2022) han realizado un estudio longitudinal para comprender cómo cambia el impacto de la gamificación en el comportamiento de los estudiantes durante un período de 14 semanas. Estos autores han encontrado evidencia empírica de que la gamificación realmente sufre el efecto de novedad, pero también se beneficia del efecto de familiarización, lo que contribuye a un impacto positivo general de este tipo de enseñanza en los estudiantes a largo plazo.

3.4 AVANZANDO HACIA EL *NETWORKING* STEAM-LÚDICO A PARTIR DE LA CREATIVIDAD

En el *networking* de enfoques educativos existe el esfuerzo de entender cada uno de los abordajes, asimismo, de compararlos y combinarlos (RODRÍGUEZ-NIETO; ALSINA, 2022). En los dos tópicos anteriores se han observado evidencias empíricas de la educación STEAM y el aprendizaje lúdico. En el sentido de combinarlos, se conjetura sobre estos dos enfoques, conforme se explica más adelante, en torno a la interdisciplinariedad y la creatividad.

La interdisciplinariedad configura el cerne de la propuesta STEAM. Conforme dicho anteriormente, en la educación STEAM se defiende que la construcción del conocimiento debe ocurrir desde contextos y estrategias didácticas que involucran, de manera significativa, diversas áreas del conocimiento, en especial las que componen el acrónimo (PERIGNAT; KATZ-BUONINCONTRO, 2019). De manera congruente a eso, durante las actividades lúdicas se propician contextos, problemas o retos que movilizan varias disciplinas para resolverlos.

Para ejemplificar la integración de varias disciplinas desde una actividad lúdica se puede recordar, por ejemplo, la propuesta de Bagiati y Evangelou (2016) dónde los niños desarrollan conocimientos y habilidades de ingeniería y matemáticas mientras juegan libremente haciendo construcciones con bloque; o cuando los niños se convierten en ingenieros para construir una máquina voladora para ayudar a un dragón en el juego guiado de Stephenson *et al*. (2021). Asimismo, mediante el desarrollo del conocimiento científico-matemático contextualizado a partir de la sensibilidad musical desde el juego tradicional de Jamaica, sugerido por Espigares-Gámez *et al*. (2020).

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Además de la interdisciplinariedad, un estudio bibliométrico evidenció que la palabra clave *creatividad* es estable en cuanto a la constitución de una línea de investigación sobre STEAM (MARÍN-MARÍN *et al.*, 2021). Conjuntamente, la creatividad ha sido un importante punto de apoyo para defender la educación STEAM en contraste a STEM, se defiende que las Artes desarrollan el pensamiento divergente y las Humanidades aportan perspectivas diferentes que complementan las áreas técnicas (PERIGNAT; KATZ-BUONINCONTRO, 2019).

En STEAM, los problemas deben admitir más de una solución posible, requiriendo del alumnado una aproximación iterativa que nos es, por lo tanto, linear y directa. En los diseños de ingeniería, por ejemplo, se hace hincapié el pensamiento creativo para encontrar soluciones a problemas que tienen diversas restricciones, frecuentemente contradictorias entre sí, tales como limitación de precio, de peso, de medidas, de propiedades de los materiales, etc. (MOORE *et al.*, 2014).

Comparablemente, la sabiduría popular concibe una relación intrínseca entre lo lúdico y la creatividad (TRUHON, 1983). Para Bondi y Bondi (2021), la propia creación de las reglas que constituyen los juegos son manifestaciones de creatividad. Ellos observan que los niños establecen reglas y restricciones para organizar su diversión. Para ellos, la creatividad puede ser concebida, por lo tanto, como la libertad en los límites de las reglas y las restricciones. Siendo así, dada la relevancia de la creatividad para la educación STEAM, cabe enfocarse en la relación entre la educación STEAM y el aprendizaje lúdico a partir de la creatividad.

El juego de aparentar es considerado como una forma de creatividad (RUSS, 1998). En esta actividad, los niños utilizan el pensamiento divergente para imaginar usos y significados inusuales de los objetos para crear historias imaginarias (HAMMERSHØJ, 2021; RUSS; DOERNBERG, 2019). Para Vygotsky (1927), incluso cuando los niños intentan imitar papeles observados previamente, necesitan ser creativos para completar las nociones vagas que suelen tener sobre estos papeles.

Para Russ (1998), hay dos categorías de procesos cognitivos importantes en la creatividad: el pensamiento divergente (que sigue en diferentes direcciones) y las habilidades de transformación (habilidad de revisar y transformar lo conocido en nuevos patrones o configuraciones). Para Hammershøj (2021), sin embargo, el pensamiento divergente es la producción de nuevas combinaciones imaginativas no necesariamente relevantes, mientras que lo lúdico es discernir sobre cuáles de estas combinaciones son divertidas. De esta manera, el autor concibe la creatividad en lo lúdico como el *humor en acción*, consistiendo en colisiones de elementos imaginativos y divertidos.

Aunque en la literatura haya divergencia sobre la evidencia empírica de relación causal entre lo lúdico y el desarrollo de la creatividad (SILVERMAN, 2016), algunos estudios evidencian que lo lúdico facilita el

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pensamiento divergente e investigaciones longitudinales encontraron que la capacidad de juego en edad temprana predijo el pensamiento creativo en un momento posterior (RUSS; DOERNBERG, 2019).

Russ (1998) sugiere que el placer en lo lúdico podría ser análogo al placer en el proceso creativo cuanto al desafío y en la resolución de problemas. Además, se rescata el significado de *ludus* para Caillois (1958), cuanto a la satisfacción del esfuerzo de ganar a través la presencia de restricciones, límites, obstáculos, enigmas y reglas.

Todo esto posibilita decir que, además del divertimiento, que por sí mismo ya sería un argumento favorable a la conexión entre lo lúdico y la educación STEAM, estos dos enfoques también están conectados a partir de la manifestación y del desarrollo de la creatividad. Ambos proporcionan situaciones donde el pensamiento divergente conduce a combinaciones imaginativas que necesitan ser evaluadas, sea un juego, sea en la resolución de un problema de ingeniería.

3.5 IMPLICACIONES DEL *NETWORKING STEAM-LÚDICO* PARA EL DESARROLLO PROFESIONAL DEL PROFESORADO

Con base en los antecedentes expuestos hasta aquí, cabe reflexionar sobre las implicaciones para el profesorado de una educación que integre el enfoque STEAM y el aprendizaje lúdico. Hay algunas especificidades de esta unión si se compara al aula tradicional: por ejemplo, tanto en STEAM como en metodologías de aprendizaje lúdico, en la interacción entre los profesores y los niños siempre habrá cierto grado de imprevisibilidad. Esto ocurre a causa de la dinámica de problemáticas abiertas, la participación activa y creativa de los alumnos. Profesores con alta tolerancia a la ambigüedad dan apoyo a la curiosidad, al riesgo y aceptan e incentivan el pensamiento divergente (TEGANO; GROVES; CATRON, 1999). Tegano *et al.* (1999) encontraron que es más probable que profesores tipificados como intuitivos y perceptivos estén dispuestos a trabajar con el lúdico; además, tienen alta tolerancia a la ambigüedad.

Sin embargo, debe haber un equilibrio. Las actividades mal diseñadas proporcionan experiencias caóticas que conducen a la confusión y la desarmonía. Estos ambientes no son propicios al éxito de desarrollo de los niños (TEGANO; GROVES; CATRON, 1999). Estudios del campo de la formación docente reportan que los profesores encuentran el planteamiento de actividades lúdicas como algo complejo y que les exige creatividad (NDLOVU; MNCUBE, 2021).

Khalil *et al.* (2022) observaron que la mayoría de los 17 profesores palestinos que ellos entrevistaron conocían el aprendizaje lúdico y más de la mitad lo incluían en sus clases. Sin embargo, también indicaron dificultades como inflexibilidad del currículo e insuficiente conocimiento debido a falta de formación sobre este enfoque. En este sentido, Rodrigues-Silva y Alsina (2022), por ejemplo, investigaron la percepción de maestros brasileños acerca del uso del enfoque lúdico. Estos autores concluyeron que lo lúdico es mejor

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percibido y más practicado entre maestros de los niveles educativos iniciales (*Ensino Fundamental*) en comparación con alumnos de más edad (*Ensino Médio)*.

Actualmente, la investigación sobre la formación docente respecto a metodologías basadas en el aprendizaje lúdico es limitada (BAKER; RYAN, 2021). López *et al*. (2021) investigaron la predisposición de profesores brasileños y españoles de matemáticas hacia la gamificación en la educación STEAM. Los autores identificaron que los profesores presentan conflictos cognitivos al valorar la gamificación y la propuesta de la educación STEAM y demuestran resistencia en llevarlo a cabo.

Con base en este diagnóstico, estos autores sugirieron que la formación del profesorado se debería llevar a cabo desde modelos que contemplen la gestión de dichos conflictos. Como el modelo realista-reflexivo, en lo cual las preconcepciones de los profesores son consideradas dentro de una formación que trabaja la teoría en simbiosis con la práctica y mediante la reflexión crítica cíclica y autorregulada (KORTHAGEN, 2010; RODRIGUES-SILVA; ALSINA, 2021).

4 DISCUSIONES FINALES

Se ha desarrollado una revisión narrativa de la literatura para explorar las relaciones entre la educación STEAM y el aprendizaje lúdico. Primero, se ha observado que existen pocas investigaciones en las bases de datos *Web of Science* y *Scopus* que reúnen directamente los términos STEAM y lúdico. Esto se justifica en parte porque, aunque STEAM y lúdico sean prometedores en la investigación educativa contemporánea, STEAM es bastante reciente ya que, como se ha indicado, fue creado en 2007 (PERIGNAT; KATZ-BUONINCONTRO, 2019) y ha ido experimentando una expansión en los últimos años, pero aún se está consolidando como línea de investigación (MARÍN-MARÍN *et al*., 2021). Esto es debido, en parte, porque a pesar del carácter novedoso de STEAM, se han encontrado trabajos que desarrollan metodologías de enseñanza del enfoque lúdico – el juego libre, el juego guiado, el juego formal y la gamificación – enmarcadas en la educación STEAM.

Después de revisar la evolución histórica de los dos enfoques educativos, se ha visualizado la existencia de una comprensión restrictiva del aprendizaje lúdico que puede haber dificultado la articulación STEAM-lúdico. Profesores e investigadores que desarrollan metodologías de enseñanza lúdicas como la gamificación con alumnos de niveles superiores, no las suelen ubicar dentro de un abordaje educativo lúdico. En consecuencia, no se establece explícitamente el *networking* STEAM-lúdico mismo cuando estas metodologías de enseñanza están enmarcadas en la educación STEAM. De esta forma, se argumenta sobre la necesidad de una comprensión amplia del aprendizaje lúdico como un espectro que contemple

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actividades menos y más estructuradas (ZOSH *et al.*, 2018). Este concepto debe ser matizado cuanto a realidades diferentes a causa de las distintas edades.

Seguidamente, se han analizado estudios empíricos que han evidenciado el éxito de la educación STEAM implementada a través de metodologías de enseñanza basadas en actividades lúdicas en todos los niveles educativos y edades. Los dos enfoques convergen desde la interdisciplinaridad, sobre todo, cuanto a la manifestación y desarrollo de la creatividad: pensamiento divergente y la proximidad de lo lúdico, por ejemplo, respecto a la satisfacción del reto de encontrar soluciones creativas a problemas con restricciones y límites (BONDI; BONDI, 2021; MINEIRO; D'ÁVILA, 2019), lo que también se ha identificado en el enfoque STEAM, en particular en los problemas de ingeniería (MOORE *et al.*, 2014).

Un punto importante de ser mencionado sobre la convergencia entre lo lúdico y la educación STEAM es respecto a la propia interdisciplinaridad. Un planteamiento lúdico involucra algún problema o desafío a ser solucionado, por fin, un contexto, en dónde inevitablemente se aplican conocimientos de diversas disciplinas. Desde la interdisciplinaridad, en STEAM se profundizan y explicitan los conocimientos asociados al acrónimo que emergen dentro de actividades contextualizadas (PERIGNAT; KATZ-BUONINCONTRO, 2019).

En síntesis, el aprendizaje lúdico y la educación STEAM son vías potentes de desarrollo de conocimientos y habilidades de manera interdisciplinar y aplicable a los distintos niveles educativos. Tal como se ha señalado, la implementación de la educación STEAM y las metodologías centradas en el aprendizaje lúdico aportan una complejidad al planteamiento didáctico (KHALIL *et al.*, 2022), lo cual requiere conocimientos que el profesorado no tiene y se puede generar cierta resistencia por una cuestión de perfil de identidad (TEGANO; GROVES; CATRON, 1999) o conflictos cognitivos respecto a estos enfoques (RODRIGUES-SILVA; ALSINA, 2021). Considerando todo este panorama, se ha identificado la necesidad de más investigaciones y formación docente que consideren el *networking* STEAM-lúdico.

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ARTICLE 5

Systematic review about students' conceptions of engineering accessed through drawings

Implications to STEAM education

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Systematic review about students' conceptions of engineering accessed through drawings

Systematic review about students' conceptions of engineering accessed through drawings: Implications to STEAM education

Jefferson Rodrigues-Silva[1*], Ángel Alsina[2]
[1] Department of mechanical engineering, Federal Institute of Minas Gerais (IFMG), Brazil, e-mail: jeffe.rodri@gmail.com
[2] Department of subject-specific didactics, University of Girona (UdG), Spain, e-mail: angel.alsina@udg.edu

Abstract: We aim to review students' conceptions of engineers and engineering accessed through their drawings. Accordingly, we enrolled in a systematic review following the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) protocols. For that, we established the Web of Science as the source of information. After applying eligibility criteria, the search resulted in ten records. We observed that many reviewed studies enrolled in research designs which contained comparisons of groups, cohorts (cross-age) or pre-post-tests. However, they generally overlooked appropriate statistical tests. Overall, the studies evidenced that most students conceive engineers as males who work individually in manual activities and outdoor environments. The major contribution of this study is providing an overview of the investigation of children's conceptions of engineering. Additionally, we call attention to the need for more research, teacher training, and carefully planned and executed activities that enhance students' conceptions of engineers and engineering instead of worsening stereotypes—especially considering current curriculum proposals, such as STEAM education embracing engineering at precollege levels.

Keywords: Draw an Engineer Test, drawing, students, precollege engineering, STEM education, STEAM education.

Introduction

Educational approaches such as STEM (Science, Technology, Engineering and Mathematics) and STEAM (Science, Technology, Engineering, Arts/Humanities, and Mathematics) have gained ground worldwide (Marín-Marín et al., 2021). Countries such as The United States of America (NGSS, 2013), Korea (KOFAC, 2012), and Spain (MEFP, 2022) have incorporated them into their curriculum. Such educational approaches place interdisciplinarity as a crucial aspect of education, especially under the claim that siloed disciplines cannot address complex matters, e.g. sustainability which encompasses economic, environmental, and social spheres (Rodrigues-Silva, Álsina, 2023a; Guyotte, 2020).

*Corresponding author: jeffe.rodri@gmail.com

Alongside interdisciplinarity, STEM or STEAM entails inserting into the precollege curriculum engineering—a discipline generally absent at this level. In this vein, discourses that promote STEM or STEAM mention the urge to increase students' interest in pursuing technical careers such as engineering, which would be highly required in a technological world (Perignat & Katz-Buonincontro, 2019). At the same time, researchers defend precollege engineering to increase girls' interest towards this career and, therefore, tackle the sustainable development goal of reducing the existent gender gap in engineering (Aurava & Meriläinen, 2022; Cabello et al., 2021, United Nations, 2015).

Conversely, practices involving precollege engineering might side effects engineering image if pedagogical planning and management overlook stereotypical conceptions (Fleer, 2021). For example, Fleer (2021) proposed a free play activity wherein preschool children were incentivised to imagine themselves as engineers while building bridges. The authors witnessed that boys mainly occupied the "engineering area"—a space with tools to design and construct the bridge—while girls avoided this area. Consequently, this activity may have reinforced their conception of engineering as a male profession. Contrary to simply incorporating engineering, Moore et al. (2014) presented a precollege engineering education framework and remarked that developing students' conceptions of engineers and engineering is essential. They argue that an accurate idea of engineering prevents reinforcing stereotypical views and gives meaning to learning the following knowledge and abilities related to engineering.

Willing to access children's conceptions of engineers, Knight and Cunningham (2004) proposed the Draw an Engineer Test (DAET) as an instrument that to explore their ideas through drawings. This instrument follows the theory of figurative thinking as the underpinning rationality of its analysis. According to this theory, children's symbolic expressions (signifiers) represent personal systems of mental images about objects (signifieds) (Piaget & Inhelder, 1971). In this sense, interpreting the results obtained through DAET is possible under the conception that children's drawings may offer insights into their mental images of engineering (Capobianco et al., 2011).

Researchers have applied this instrument in countries like the United States, China, and Turkey (Capobianco et al., 2011; Diefes-Dux & Capobianco, 2011; Knight & Cunningham, 2004). Results from those studies highlighted problems such as children's misconceptions of engineering that might prevent them from envisioning it as an intellectual activity. Additionally, from a very early age, children already express gender bias toward engineering as a male career. Such an image likely averts some girls from pursuing this profession.

In sum, countries gradually adopt educational approaches incorporating engineering at precollege levels; studies identify children expressing misconceptions about engineering and gender bias, and weakly structured activities are likely to worsen those misconceptions. This configuration conduces to two research questions. First, how have students' conceptions of engineers and engineering been investigated through drawings? Furthermore, what are students' conceptions of engineers and engineering?

Currently, no systematic review addressed studies exploring students' engineering conceptions through their drawings. In this sense, the literature lacks studies that provide an overview of this topic. Line up to those interrogations and the identified gap in the literature. We aim to review students' conceptions of engineers and engineering accessed through their drawings.

Methods

Considering this research goal, we enrolled in a systematic literature review following the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) protocols. Accordingly, the investigation process is informed to guarantee its rigour and reproducibility (Moher et al., 2015). It was structured into the phases: 1) Search elements and Boolean logic, 2) Eligibility criteria, 3) Information sources, 4) Data collection, and 5) Data analysis.

Search elements and Boolean logic

First, we identified *engineer* and *engineering* as central terms of the research goal. Then, the words *draw* and *drawing* were acknowledged as appropriate terms to filter studies that applied drawings to access people's conceptions. Two additional words, *conception* and *stereotype*, were considered to refine the search in order to prevent finding studies on engineering technical drawing. Given all that, the Boolean logic was created: ENGINEER* and DRAW* and (CONCEPTION or STEREOTYPE). Moreover, we established that the word *engineer* should be scanned in the title—given its centrality in this study—and the other terms of the Boolean logic in the title, abstract, author, keywords, or keywords plus.

Eligibility criteria

In this second phase, we established the eligibility criteria applied in this review, as presented in Table 1. First, we fixed that the documents should be peer-reviewed because this evaluation indicates some research quality. Following this, we established that the records could have the format of an article or conference proceedings. We included documents published since 2004, which correspond to when the DAET instrument was created by Knight and Cunningham (2004). Since we are interested in students' conceptions, we secure that the document was classified in the educational research area and the population was centred on students. Finally, we included documents published in English because it is considered a universal language in the current scientific community. Moreover, we were open to considering Spanish and Portuguese documents to profit authors' knowledge in those languages to broaden the research scope. The exclusion criteria were essentially antonyms of the inclusion ones.

Table 1
Eligibility criteria

Criteria	Inclusion	Exclusion
Type of document	Article or conference proceedings	Other formats
Publication period	From 2004 to 2022	Before 2004
Research area	Education	Other areas
Population	Students	Teachers and student teachers
Language	English, Spanish, and Portuguese	Other languages

Information sources

In this third phase, we selected the Web of Science (WoS) index from Clarivate as the information source because of its recognised rigour and importance in science, particularly in the educational field.

Data collection

Once the Boolean logic, the eligibility criteria, and the source of information are established, we finally move to the review's fourth phase, which consists of collecting and treating data. A scan enrolled on 30 October 2022 resulted in 74 records. We used the WoS platform to filter the type of document, publication period, research area, and language. After that, we read the abstract and full texts to ensure the documents included were correct—DAET instrument and focused on students.

At this point, we observed that three articles were non-eligible—Thomas et al. (2020, 2016) had to be discarded because they were focused on students but developing a rubric and validating a modified version of the DAET, and Diefes-Dux and Capobianco (2011) study because they presented a specific analysis of data from another study which was already contemplated in the list of reviewed articles (Capobianco et al., 2011). Eventually, as shown in Figure 1, the data collection process was conducted to a final list of ten documents—articles and conference proceedings.

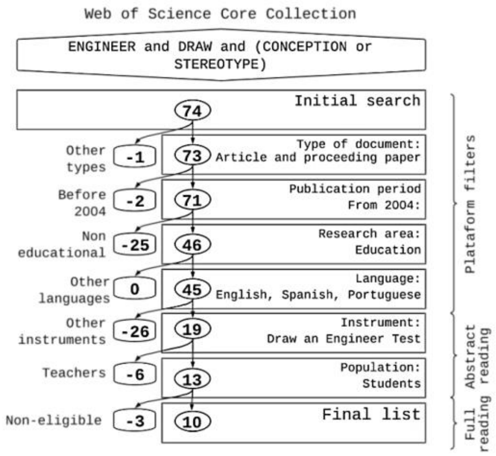

Figure 1. Data collection process.

Data analysis

We used the Atlas-ti program to provide the word occurrence from those ten selected articles. For this, we excluded numbers and set the threshold of 80 accounts. Then, we plotted the information in word cloud format to visually analyse the accuracy of those documents concerning the Boolean logic and the research goal.

During analysing data, we did several reads and comparisons between the documents. We observed categories of information that could be organised into three blocks:

- **General research features:** methodology approach, sample size, design, intervention, educational level, publication year and region;
- **Data collection instrument and procedure details:** the instruction for making the drawing, the instructions and questions asking for a description of the drawing, application time, applicants, and complementary interviews;
- **Common results**: students' conception of gender (male or female), place of work (outdoor or indoor), activity (manual or intellectual), and work setting (individual or collective). Moreover, we addressed the interventions, gender, and age comparisons.

For this last part regarding studies' typical results, whenever necessary, we recalculated the frequency percentages of the four variables— students' conception of gender, place of work, activity, and work setting— considering the total sample size of each study. Matusovich et al. (2021), for example, represented the results of students' opinions on engineering activities through a horizontal bar chart. In this case, we had to estimate the values using the scale presented in the figure.

Moreover, we run one-sample proportion tests on Statistical Package for the Social Sciences (SPSS) program to verify whether the frequency differs statistically between the levels of each variable—using a threshold of 5% of significance. Furthermore, researchers were not always able to interpret, for example, the gender portrayed in the drawings; children may not have pictured a human figure or represented both. Therefore, we created an extra class for each variable to account for indiscernible information from drawings.

Regarding the conception of engineers' activities, we accounted as manual undertaking: fix, build, construct, repair, drive, make a single product (craft), and operate machines. Furthermore, as an Intellectual undertaking, the activities: create, optimise, invent, design, supervise/observe, use math, use science, use technology, solve problems, research, experiment, test, and teach. We clarify that occasionally, engineers can be involved with all those activities, but engineering primarily deals with highly complex issues that demand more cognitive abilities (Moore et al., 2014).

We did not further the review aspects evaluated by a few researchers, such as skin colour (Ergun & Balcin, 2019; Fralick et al., 2009), smiling faces (Ata-Aktürk & Demircan, 2021a), and the presence of engineers in students' family (Capobianco et al., 2011).

Results

Now on, we present the review results. Beforehand, we highlight the scarcity of studies exploring students' conceptions of engineering since only ten documents were eligible. In Figure 2, a word cloud demonstrates that the terms *engineers*, *drawn*, *students*, *education*, and *conceptions* are *frequently* written in the reviewed documents. This result confirms a substantial relationship between the selected manuscripts and our research goal. Additionally, we call attention to the words *test*, *DAET*, *gender, design,* and *STEM occurrence.* Those elements will be further addressed in this review.

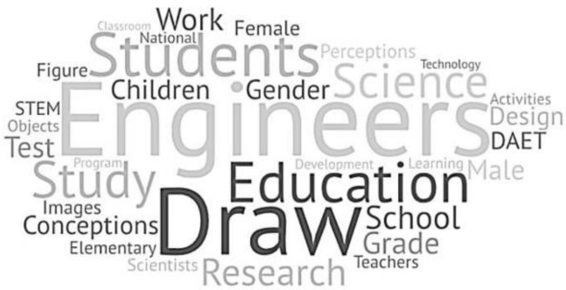

Figure 2. Word cloud of the reviewed documents.

Review of general research features

Table 2 summarises the first block of information that explores general research features: author, year of publication, region, educational level, sampling, sample (N), intervention, grouping, design, and statistics. It is observable that authors contributed with only one record each, which indicates that no researcher could be considered an exponent of the topic. Regarding geographic distribution, the United States of America outstand as the country with more studies—six in total. Turkey has two studies, while China and Mexico have only one each.

Table 2

General research features

Author	Region	Level	Sampling	N	Interven-tion	Grouping	Design	Statistics
Ata-Aktürk and Demircan (2021a)	Turkey	Preschool	Purposeful	436	No	One	Cross-sectional	Descriptive
Capobianco et al. (2011)	United States	Elementary school	Purposeful	396	No	One	Cohort (1-5th grade)	Chi-Square
Carr and Diefes-Dux (2012)	United States	Elementary school	Purposeful	173	Yes	One	Cohort (2-4th grade) and pre-post	Descriptive
Chou and Chen (2017)	China	Elementary school	Purposeful	750	No	Two (urban and suburban areas)	Cohort (4-6th grade)	Descriptive
Ergun and Balcin (2019)	Turkey	Middle School	Purposeful	119	No	One	Cross-sectional (5-7th grade)	Descriptive
Fralick et al. (2009)	United States	Middle School	Purposeful	744	No	One	Cross-sectional	Descriptive
Knight and Cunningham (2004)	United States	Elementary and Middle School	Purposeful	384	No	Two (male and female students)	Cohort (3-9th grade)	Descriptive
López et al. (2013)	Mexico	Higher education	Purposeful	124	No	Two (public and private universities)	Cross-sectional	Descriptive
Matusovich et al. (2021)	United States	Middle School	Purposeful	757	Yes	One	Pre-post	Descriptive
Rivale et al. (2020)	United States	Elementary school	Purposeful	355	Yes	Two (male and female tutors)	Pre-post and two cohorts	ANOVA

Note: Cohort here is understood as a longitudinal-like design conceived through a cross-sectional collection of data, which means participants responded only once, but they have similarities that permit inferring a temporal relationship.

Table 3

Data collection instrument and application procedure details

Author	Instruction for drawing	Description of the drawing	Time (min)	Applicant	Complementary Interview
Ata-Aktürk and Demircan (2021a)	Draw an engineer at work	Children were assumed as illiterate	20	Teachers	What is happening in your drawing? Is there an engineer in this drawing? What is this engineer doing?
Capobianco et al. (2011)	In the space below, draw an engineer doing engineering work	What is your engineer doing?	30	Teachers	Is your engineer a boy or a girl? What is the engineer doing? What can you tell me about this person? Complete: an engineer is a person who...
Carr and Diefes-Dux (2012)	Draw an engineer doing engineering work	Write about what this engineer is doing	-	-	No
Chou and Chen (2017)	How do engineers look? Please, draw an image of an engineer	Give a name to your engineer. Where does your engineer work? What is your engineer doing?	30	Teachers	30 unstructured interviews
Ergun and Balcin (2019)	Draw a picture of an engineer at work	Give a name to your engineer. What are the personal characteristics of an engineer? How is the work environment of an engineer? What kinds of work does an engineer do? What is the engineer you drew doing?	45	Researchers	No
Fralick et al. (2009)	Draw an engineer at work	Engineer's name. Describe your engineer a) personal information, b) Work setting, c) Job description. What is the engineer in your drawing doing?	-	Teachers	No
Knight and Cunningham (2004)	Draw a picture of an engineer at work	What does an engineer do?	15	Teachers	No
López et al. (2013)	Participants were asked to close their eyes and imagine an engineer at work. Then they were required to draw it	Describe what the engineer is doing in your drawing. List at least three words/phrases that come to mind when you think of an engineer. What kinds of things do you think an engineer does?	25	Researchers	28 unstructured interviews
Matusovich et al. (2021)	Draw a picture of an engineer at work	What does an engineer do? Do you know any engineers? Who are they?	15	Researchers	No
Rivale et al. (2020)	Draw a picture of what an engineer looks like	Name one thing invented by an engineer	-	-	No

As presented in Figure 3, the reviewed documents are steadily distributed in time. Despite some gaps, since DAET's creation in 2004, there has been no production peak and a maximum of two papers published during the same year.

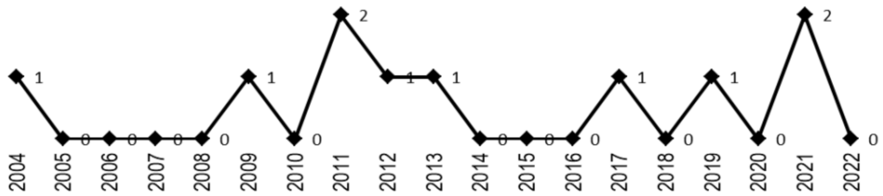

Figure 3. Time distribution of publications on the Web of Science of studies on students' conceptions of engineering through drawings.

Then addressing students' educational level, most documents investigated elementary or middle schools. Ata-Aktürk and Demircan (2021a) explored preschool students replacing the DAET written part with a short interview about the drawing (different modifications of this instrument will be seen later on). Studies on higher education were not frequent either. López et al. (2013) addressed higher education to observe how incoming engineering students conceive their course.

Figure 4. Educational levels addressed in the reviewed articles.

All studies followed purposive sampling and a non-randomised selection method—strategies commonly used in qualitative research. In this case, investigators select the participants from a particular context or reason (Lawson et al., 2019). However, studies have relatively large samples of qualitative research standards. Figure 5 shows the sample size distribution: three studies have between 100 and 200 participants; four studies lay in a middle range of 350 to 450 participants, and the last three pieces of research had extensive samples with more than 700 participants each.

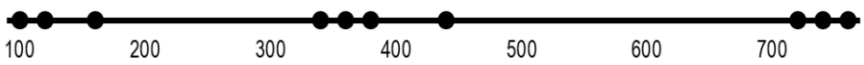

Figure 5. Sample size distribution of the reviewed articles.

Studies applied the DAET as their primary research data collection instrument. Consequently, they used similar strategies to analyse data—basically inducing categories by contrasting the drawings and the explanations about it provided by open-ended questions or complementary interviews. Nonetheless, researchers reached no consensus on whether this configuration of inquiry has a qualitative, quantitative or mixed approach. The confusion may be because the information source is qualitative, but subsequently, categories are created and treated as constructs with frequency quantification.

Ata-Aktürk and Demircan (2021a), for example, specified that their study had a phenomenography approach. They presented a cross-sectional study, no comparison groups, and not aiming to evaluate an intervention. Coherently to a qualitative approach, they focused on exploring the quality (phenomenon) of students' conceptions of engineers and engineering. In contrast, Capobianco et al. (2011) reported using qualitative data but, coherently to a (cross-age) cohort design, they had a quantitative part and, therefore, applied statistical testing. Similarly, Rivale et al. (2020) also used statistical tests (ANOVA). We clarify that here cohort is understood as a longitudinal-like design but through a cross-sectional data collection. It means participants respond only once, but as they keep common characteristics (being students), they are related to each other regarding the different grades, so we can infer a temporal change (Lawson et al., 2019).

The remaining seven documents have at least one comparison condition: two groups, cohort design, intervention and a pre-post design (results of those articles will be explored later on). Notwithstanding, they present only descriptive statistics, and frequencies are directly compared without running hypothesis testing. Figure 6 shows the methodological panorama of the reviewed articles. We highlighted that "two groups", "cohort or pre-post design", and "intervention" are comparison conditions that should inherently be accompanied by hypothesis testing.

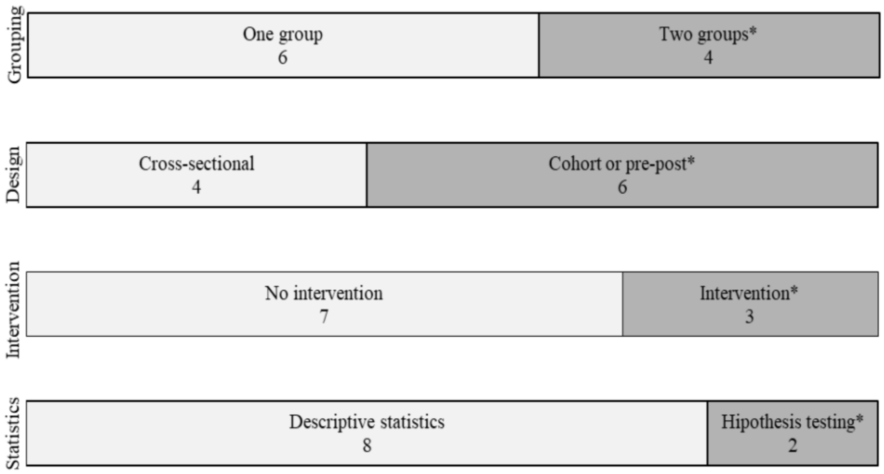

Figure 6. Methodological panorama of the reviewed articles.

Review of data collection instrument and procedure details

In the following paragraphs, we explore the second block of information concerning the data collection instruments of the reviewed documents. As stated earlier, authors used the DAET as their primary research instrument, but with some variations and adaptions (Table 3). Next, we address the

DAET regarding the instruction for drawing, description of the drawing, time of application, applicant, and complementary Interview.

Knight and Cunningham (2004, p. 3) created the DAET with the primary instruction, "Draw a picture of an engineer at work." After that, the authors repeated this instruction in their research. Following the same idea, López et al. (2013) asked students to close their eyes, imagine an engineer at work, and then draw it. Differently, Chou and Chen (2017, p. 478) concentrated on engineers' appearance. They wrote, "How do engineers look? Please, draw an image of an engineer". Similarly, Rivale et al. (2020, p. 22.552.5) used, "Draw a picture of what you think an engineer looks like".

Additionally to DAET's primary instruction, Knight and Cunningham (2004) included the open-ended question, "What does an engineer do?" to help interpret students' drawings regarding the engineering activity. Equally, all authors had those auxiliary requests. However, while some of them kept the question about the general action of engineers (López et al., 2013; Matusovich et al., 2021), other authors modified it to address what the portrayed engineer was doing in the drawing (Capobianco et al., 2011; Carr & Diefes-Dux, 2012; Chou & Chen, 2017; Ergun & Balcin, 2019; Fralick et al., 2009). Additionally, three studies demanded the participants to name their engineers—helpful information for gender interpretation—and to describe the work environment (Chou & Chen, 2017; Ergun & Balcin, 2019; Fralick et al., 2009). Any question directly requests the gender and the working setting—whether the engineer works individually or collectively.

Rivale et al. (2020) required students to cite one thing invented by engineers before drawing. This approach will likely have biased students to conceive engineers as inventors/designers.

In half of the reviewed studies, researchers counted on teachers to be the applicants of the DAET. Some authors commented on how teachers were prepared to do it properly. For example, Capobianco et al. (2011, p. 310) remark that "teachers were provided written directions describing the procedures for administering the drawing test". Also related to the application of the DAET, the average time designated to it was 25 minutes (SD 10 minutes).

Moreover, four studies mentioned an interview to clarify the drawings' reasons. Among those interviews, we highlight the work of Capobianco et al. (2011, p. 310), the sole document that reported directly addressing gender, "Is your engineer, boy or girl?". We also remark that Ata-Aktürk and Demircan (2021a) applied the Draw-and-tell technic—a quick (5 min) and informal narrative about the drawing. They claimed this strategy was an age-appropriate way of working with preschool students who were assumed illiterate and could feel uncomfortable with formal interviews.

The idiom is likely to influence children's image of engineering. For example, Chou and Chen (2017) consider that students might conceive engineering as manual work because the word *labourer* in Chinese shares its initial character with the word *engineer*. Similarly, Knight and Cunningham (2004) observed that some students' answers indicated a vocabulary problem in English that may have misconducted their conception of engineering. They explain that students probably related engineering with the word *engine* and associated this profession with cars. For instance, one student wrote, "Engineer has the word engine in it, so I guess they must work with engines".

In this same vein, López et al. (2013) warn that the Spanish language places genders to nouns, so they included male and female engineers (*ingenieros* y *ingenieras*) in the DAET instrument. However, explicitly naming male and female engineers may have influenced the children to consider both genders. Silva-hormazábal et al. (2022) proposed a STEAM activity of interdisciplinarity between engineering and mathematics using a Spanish version of the DAET. They suggested writing the expression "draw a person that does engineering—*dibuje una persona que hace ingeniería*" because "*persona"* is a gender-neutral term.

Review of common results

Next, we review the results of the articles. As stated in the methodology, we identified aspects commonly studied between the documents, viz., students' conception of engineers' gender, place of work, activity, and work setting. Table 4 presents the frequency distribution of those aspects considering the total sample of each study—we bold the proportions statistically differently. We gathered individuals from all groups and cohorts and considered only the pre-test results.

Table 4

Typical results regarding students' conception of engineers' gender, place of work, activity, and work setting

Author	Gender			Place of work			Activity			Work setting		
	Male	Female	Indiscernible/both	outdoor	Indoor	Indiscernible/both	Manual	Intellectual	Indiscernible/both	Individual	Collective	Indiscernible/both
Ata-Aktürk and Demircan (2021a)	**46%**	**19%**	36%	**34%**	**6%**	60%	**70%**	**4%**	25%	**71%**	**4%**	25%
Capobianco et al. (2011)	**58%**	**18%**	24%		-		**72%**	**6%**	22%		-	
Carr and Diefes-Dux (2012)		-			-		**69%**	**8%**	24%		-	
Chou and Chen (2017)	**80%**	**16%**	4%	73%	-		**55%**	**35%**	10%		-	
Ergun and Balcin (2019)	**87%**	**12%**	2%	**56%**	**35%**	10%	**36%**	**44%**	20%	**87%**	**13%**	0%
Fralick et al. (2009)	**49%**	**13%**	38%	**32%**	**15%**	51%	**42%**	**16%**	42%	**79%**	**21%**	0%
Knight and Cunningham (2004)	15%	10%	75%		-		**67%**	**27%**	6%		-	
López et al. (2013)	**69%**	**23%**	8%		-		**-**				-	
Matusovich et al. (2021)		-			-		**24%**	**62%**	14%		-	
Rivale et al. (2020)	**55%**	**17%**	28%		-		-				-	

Note: Multiple one-sample proportion tests show that frequencies of detectable levels of each category are statistically different, considering a significance threshold of 5%—highlighted in bold. Except for the gender distribution (male/female) in the work of Knight and Cunningham (2004).

Engineers' gender and engineering activity are the most studied domains, followed by the place of work and work setting. We comment that Knight and Cunningham (2004) had an oddly high level of indiscernible gender (75%). Those authors explained that about half of the drawings were "stick figures", which prevented discerning the representation of gender. Additionally, they explain that they observed an unusually higher occurrence of drawings depicting female engineers because two female undergraduate engineering students had worked with those students for a few months before the instrument application.

In this respect, we observed that researchers used stereotypical features associated with gender to analyse the drawings. López et al. (2013) explained that they considered dress, skirt, long hair, painted lips, and long eyelashes as female characteristics. Knight and Cunningham (2004) explained that they regarded short hair, square shoulders, and necktie as male characteristics, while long hair was considered a female trait. Researchers used questions to address gender so that such stereotypical analysis could be avoided. For example, Capobianco et al. (2011, p. 310) used the open-ended question, "Is your engineer a boy or a girl?" Differently, Fralick et al. (2009) demanded that the children give a name to their engineers so that this information could help infer the gender.

Matusovich et al. (2021) plotted a bar chart which shows that students' responses to an open-ended question on what engineers do have a high frequency of intellectual tasks such as design, solving problems, and using math and science. However, analysis associated with their drawings evidenced the verbs building and fixing and the nouns vehicle and tools, which are terms more closely related to manual tasks. Similarly to other studies, blueprints had a much lower occurrence.

In the sequence, we present Figure 7, which shows the aggregated results to account for a mean frequency distribution throughout the reviewed studies regarding students' conception of engineers' gender, place of work, activity, and work setting. Notably, students primarily conceive engineers as males who work individually in manual activities and outdoor environments.

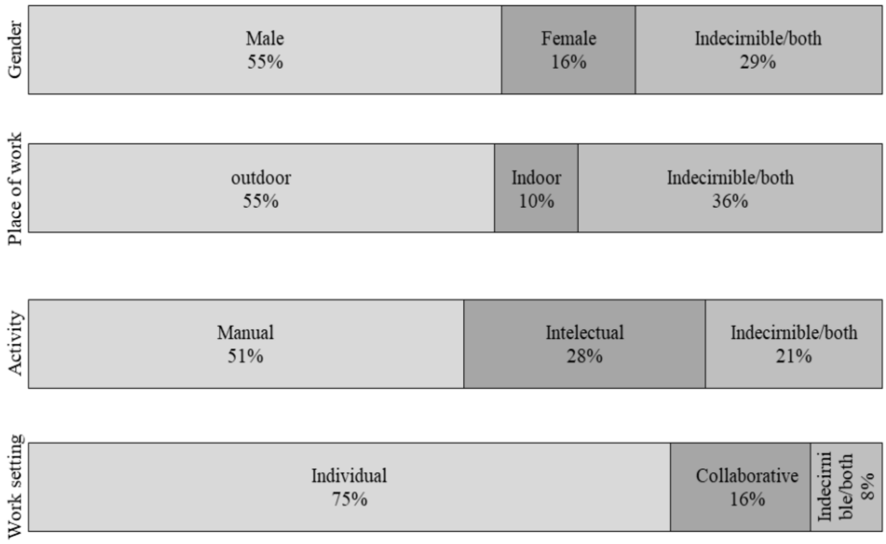

Figure 7. Aggregation results regarding students' conception of engineers' gender, place of work, activity, and work setting.

Researchers observed that girls draw more female engineers than boys. However, both girls and boys draw more male engineers in total (Chou & Chen, 2017; Knight & Cunningham, 2004). Despite the difference in gender representation, girls and boys have similar conceptions of engineers and engineering—activity, place of work and work setting (Chou & Chen, 2017).

Moreover, a more significant proportion of students from lower grades represent engineers incorrectly as other professions, such as doctors and bombers, while higher grades demonstrate more accurate views of engineering activity. However, Ergun and Balcin (2019) observed that the frequency of female engineers' portrayed decreased among students from higher grades. Similarly, Chou and Chen (2017) concluded that younger students (4th grade) were more likely to picture female engineers compared to older ones (5th and 6th grades).

Now addressing the interventions enrolled in the reviewed articles, Carr & Diefes-Dux (2012) studied teachers who participated in a professional program designed to increase technological literacy and knowledge of the roles and types of engineers. For that, those teachers engaged in interdisciplinary engineering, math and science activities. Then, teachers were asked to practise at least one engineering design activity in their class. DAET showed that the number of students who conceived engineers as designers increased from 5 to 80 in a pre-post configuration. Qualitatively, the authors observed students portrayed engineers designing various objects such as bicycles, clocks, and a safer playground. They concluded that the teacher training on engineering had a positive outcome since it eventually impacted students' conceptions of engineering.

Additionally, gender representativeness seems influential in students' conception of engineering. Rivale et al. (2020, p. 22.552.8) comment that the gender of the tutor who conducted engineering activities impacted the frequency of female characters' drawings among the girls. According to them, "81% of the girls taught by a female fellow drew a female engineer, compared to 41% of the girls taught by a male fellow".

Notably, depending on the subject and pedagogical approach, engineering activities may reinforce the stereotype of engineering as manual work. For example, Matusovich et al. (2021, p. 894) proposed some engineering activities, such as the maintenance of a flashlight. Throughout the activities, they also reported discussions centred on subjects such as cars and buildings. Afterwards, the authors observed students' images of engineering distanced from cognitive tasks. Such a non-intellectual perception hindered them from seeing engineering as a field connected to other knowledge areas, such as mathematics and science.

> Data revealed an increase in the frequency of responses coded as having the root terms of *fix*, *build*, and works on with a decrease in the frequency of the root terms *create*, *help*, and *design* when comparing pre and post-classroom engagement responses. Although low to start with, responses about using math and science and solving problems declined further on the post-test (Matusovich et al., 2021, p. 894).

Some researchers also analysed objects portrayed. Ata-Aktürk and Demircan (2021a), e.g. report that almost half of the drawings presented civil structures such as houses, schools, and roads. Comparatively, design-related objects were found in approximately 6% of them. Likewise, Chou and Chen (2017) highlighted that elementary children tended to draw civil structures and workers with tools such as cranes or drilling machines. The authors pinpoint that few images included design-based architectural engineers who created blueprints for residential buildings.

Discussions

We aimed to review students' conceptions of engineers and engineering accessed through their drawings. Accordingly, we discuss the results of this literature review regarding the two research questions. Initially, we inquire how students' conceptions of engineers and engineering have been investigated through drawings.

First, we identified a dearth of research investigating students' conceptions of engineering through drawings, especially at the preschool level. One point that explains the literature gap is that engineering was traditionally absent at precollege levels (Moore et al., 2014). In this regard, we highlight the increasing interest in interdisciplinary approaches such as STEAM education—referring to integrating Science, Technology, Engineering, Arts/Humanities, and Mathematics (Marín-Marín et al., 2021; Rodrigues-Silva & Alsina, 2023b). Countries like The United States (NGSS, 2013), Korea (KOFAC, 2012), and Spain (MEFP, 2022) are recently adopting those interdisciplinary approaches in their curricula. This curricular change inherently incorporates engineering at school, which could foster investigations regarding students' conceptions of engineering. Especially addressing the lack of research in preschool, this stage has historically received less attention in research than other educational levels. Preschool is not mandatory in many countries, and it comprises a diversity of organisational formats (Davis, 2009). Such complexity is accompanied by specific ethical considerations to investigate very young children that may discourage some researchers (Abbott & Langston, 2005). Particularly referring to inquiry on students' conceptions of engineering, perhaps some researchers felt the DAET instrument was inappropriate for early children due to its written part. Notwithstanding, we suggest the strategy used by Ata-Aktürk and Demircan (2021a); they assumed preschoolers were illiterate and complemented the instrument with the Draw-and-tell technique, consisting of informal and quick questions while children draw.

Additionally, we suggest investigations using DAET should be held in different parts of the world since the current ones are concentrated in the United States. Different cultural and socio-economic backgrounds can influence children's conception of engineering. Some researchers, for instance, observed that children's native language impacts children's understanding of engineering activities (Chou & Chen, 2017; Knight & Cunningham, 2004; López et al., 2013).

We highlight that many studies underwent quantitative research, including comparison groups, cohort (cross-age) or pre-post-test designs. However, they generally identified their methods as qualitative approaches and lacked statistical tests. In those cases, we suggest that authors embrace mixed research methodologies—while having qualitative data nature, they ought to use appropriate hypothesis testing if enrolling in such designs. Additionally, DAET could complement other research instruments to understand children's engineering conception comprehensively. Some studies have already applied complementary interviews (Capobianco et al., 2011; Chou & Chen, 2017). Likewise, researchers could combine it with concept mapping, focus groups, and surveys. Beyond the instruments mentioned, we highlight the potentiality of incorporating DAET in case studies that explore children's involvement in engineering-related activities. Accordingly, field observations, video recordings, and evaluations of their productions could provide valuable insights into their engineering conceptions.

Regarding the data collection instrument, the authors made minor modifications in the DAET, mainly regarding the complementary questions about the drawing. We suggest that, once children have finished their drawings, authors should consider using complementary questions about students' conception of gender, place of work, activity, and work setting portrayed. That way, researchers prevent applying bodily stereotypes such as long hair, eyelashes, and clothing to analyse portrayed genders. In addition, the indiscernible information rate will probably reduce.

In this same direction, Thomas et al. (2020, 2016) proposed a modified version of DAET, which explores students' opinions about how engineering is connected to mathematics and science. This contour may be attractive considering educational approaches such as STEAM education, which proposes integrating Science, Technology, Engineering, Arts/Humanities, and Mathematics knowledge areas (Perignat & Katz-Buonincontro, 2019). Additionally, using DAET consistently, such as adopting their version, would enhance the comparability of results among future studies.

For this literature review, we also query—what are students' conceptions of engineers and engineering? Overall, researchers concluded that students conceive engineers as males who work individually in manual activities and outdoor environments. Those conceptions are observed from a very early age, and they are likely to be a response to different sources of information. In this vein, the literature has shown that children's picture books carry misconceptions and gender stereotypes about engineers and engineering (Ata-Aktürk & Demircan, 2021b).

We verified that researchers qualified and quantified various actions related to engineering—such as fixing, constructing, observing and designing—but their conclusions were commonly centred on whether portrayed engineers were pursuing manual or intellectual tasks. Even though engineering may sometimes be involved in manual actions or processes, engineers are not likely to be those who physically execute them. Accordingly, we suggest differentiating one simple product construction from conceiving a product that will be reproduced. The former is more connected to crafting, while the latter relates to engineering design.

The reviewed studies showed that older students perceive engineers more accurately as designers. Cohort studies with appropriate statistical comparisons are needed to check whether older students tend to view engineering as a collective, intellectual, and indoor activity. However, studies already point out that gender stereotypes intensify with age. Those findings reinforce the urge to address Education for Sustainability (EfS) since Early Childhood Education (ECE) (Rodrigues-Silva & Alsina, 2023a; UNESCO, 2008), precisely the sustainable development goal of pursuing gender equity (United Nations, 2015). In this sense, while studies with DAET evidence gender stereotypes, to an extent, they indicate the necessity of developing strategies to inverse the critical gender inequality in technical areas. Ata-Aktürk and Demircan (2021a), for example, evidenced that picture books for children aged 3 to 6 years from Turkey mainly represent engineers as male characters. Accordingly, the authors suggest increasing children's contact with cultural content developed through a gender-inclusive prism. In a similar direction, Knight and Cunningham (2004) indicated that exposing children to female engineers' role models likely increased their perception of women in engineering. Furthermore, parents' and teachers' conceptions of engineering should be explored and developed so children's environment and social interaction do not transmit and reinforce gender stereotypes—studies utilising DAET with teachers observed they similarly represent more male engineers (Vo & Hammack, 2022).

Teacher education is vital for effectively addressing and challenging these stereotypes in engineering. Literature warns that poorly planned activities in engineering worsen stereotypical gender (Fleer, 2021; Matusovich et al., 2021). Gender equality concerns could be incorporated into teacher training programs focused on developing teachers' STEAM planning ability (Rodrigues-Silva & Alsina, 2022).

STEAM education fundamentally requires beyond diagnosticating students' conceptions of engineers and engineering and providing pedagogical strategies to develop such conceptions. In this sense, Moore et al. (2014) recommend a framework wherein they claim the conception of engineers and engineering must be a topic for precollege engineering teaching.

Therefore, there is a need for activities that enhance the conceptions of engineering. Knight and Cunningham (2004) incentivised the teacher applying the DAET to seize the opportunity and have a discussion class about engineering after the students responded to the instrument. In this vein, Silva-Hormazábal et al. (2022) proposed a STEAM activity wherein students from primary education responded to the DAET and then enrolled in a statistical investigative cycle. Children formulated hypotheses and analysed their drawings in class. For that, students count the frequency of similar categories presented in this review, such as gender, and eventually, they discuss the results.

Studies show that teachers lack knowledge about STEAM as an educational approach (López et al., 2021). Overall, the literature in STEAM education carries misconceptions of engineering and frequently reduces it to crafting. Specifically, teachers report unfamiliarity and difficulty integrating engineering and technology into their lesson plans (Rodrigues-Silva & Alsina, 2022). In this sense, studies using DAET showed teachers present similar misconceptions of engineers and engineering of those to the students (Hammack & Vo, 2019; Vo & Hammack, 2022). Notwithstanding, we should highlight that an inappropriate pedagogical approach to engineering may induce misconceptions about it. This unintended effect occurred, for example, with the interventions reported by Matusovich et al. (2021), wherein students did activities such as fixing flashlights and discussing cars and civil constructions. Pre and post-test indicated that more students perceived engineering as manual work. In this case, the pedagogical planning of those activities failed to remark that engineers are involved with electrical devices, machinery, and civil structures, but their activity is not about manually fixing or constructing them. On the contrary, engineers deal with intellectual tasks such as designing electrical devices, machinery, and civil structures; and planning and supervising production and maintenance processes.

Conclusions

The major contribution of this study is providing an overview of the investigation of children's conceptions of engineering through their drawings. There were no similar previous systematic reviews, and related work concerns empirical studies which address specific regional contexts.

The results of this review allow drawing some conclusions on exploring children's conceptions of engineers and engineering:

- There is a dearth of studies investigating students' conceptions of engineering through drawings;
- Researchers should converge DAET instructions to help comparability of results and prevent misguided analysis such as applying stereotypes to identify genders;
- Researchers undergo complex research designs such as comparison groups, cohort (cross-age) or pre-post-test using DAET. However, those studies frequently lack appropriate statistical tests;
- At a very early age, children already exhibit misconceptions or stereotypes of engineering as a profession of men working individually in manual activities and outdoor environments;
- Teachers must have the proper training to embrace precollege engineering activities. Otherwise, they will likely enrol in poorly designed activities that worsen misconceptions about engineering.

The study provides exciting insights for research and educational practices, especially considering the current interest in engineering in interdisciplinary STEAM education and the aspiration of a sustainable society which pursues gender equity. Among the future directions, we highlight using the draw-and-tell technique for more studies in preschool age. Consistently writing DAET instructions and questions for drawings descriptions, such as proposed by Thomas et al. (2020, 2016) version, to enhance comparability among the studies. Asking children directly about the gender portrayed prevents applying stereotypes to infer gender representations. Finally, conceiving activities explicitly addressing engineering and placing it more accurately as an intellectual practice instead of one product construction such as crafting.

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Conflict of interests

The authors declare no conflict of interest.

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Gmail **Jefferson Rodrigues-Silva <jeffe.rodri@gmail.com>**

[IJCRSEE] Editor Decision

2 mensagens

Dr. Lazar Stosic <editor@ijcrsee.com> 29 de maio de 2023 às 15:08
Para: Jefferson Rodrigues-Silva <jeffe.rodri@gmail.com>, Ángel Alsina <angel.alsina@udg.edu>

Jefferson Rodrigues-Silva, Ángel Alsina:

We have reached a decision regarding your submission to International Journal of Cognitive Research in Science, Engineering and Education (IJCRSEE), "Systematic review about students' conceptions of engineering ac-cessed through drawings: implications to STEAM education".

Our decision is to: Accept Submission

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ARTICLE 6

Student's conceptions of engineering and its connections with mathematics and science

Rodrigues-Silva, J., & Alsina, Á. (in press). Students' conceptions of engineering and its connections with mathematics and science. *Enseñanza de las Ciencias*.

Concepciones del alumnado sobre ingeniería y sus conexiones con las matemáticas y las ciencias

Jefferson Rodrigues-Silva

Departamento de Ingeniería Mecánica. Instituto Federal de Minas Gerais, Arcos, Minas Gerais, Brasil

jeffe.rodri@gmail.com

Ángel Alsina

Departamento de Didácticas Específicas, Universidad de Girona, Girona, Cataluña, España

angel.alsina@udg.edu

RESUMEN

Considerando la incorporación progresiva de la competencia STEM en el currículo de educación primaria, se exploran las concepciones del alumnado sobre la ingeniería. Para ello, se ha aplicado el instrumento validado *Draw an Engineer Test* (mDAET) a 18 estudiantes españoles de 10 a 11 años. Los datos obtenidos a partir de una metodología mixta (por un lado, estadística descriptiva y pruebas no paramétricas; y, por otro, análisis de contenido) muestran que el alumnado participante presenta nociones estereotipadas de ingeniería como actividades manuales, desarrolladas en ambientes de trabajo de campo y de forma individual. Además, identifican un uso simplista de las matemáticas y no visualizan el uso de las ciencias en ingeniería. Se defiende que es necesario el desarrollo profesional docente para abordar estas concepciones y, así, avanzar hacia la educación interdisciplinar STEM o STEAM.

Palabras clave: Concepciones sobre ingeniería, educación matemática, educación científica, STEAM, educación primaria.

1. INTRODUCCIÓN

En las últimas dos décadas, diversas investigaciones han utilizado el test “Dibuje una Persona que hace Ingeniería” (*Draw and Engineer Test* – DAET) (Knight y Cunningham, 2004) para explorar las concepciones de niños y niñas sobre el área y la profesión de ingeniería. Estos estudios han sido desarrollados en países como Estados Unidos (Capobianco et al., 2011; Matusovich et al., 2021; Rivale et al., 2020), Turquía (Ata-Aktürk y Demircan, 2021; Ergun y Balcin, 2019), México (López et al., 2013) y China (Chou y Chen, 2017).

Los resultados de estos estudios han evidenciado que el alumnado de estos países posee concepciones equivocadas y estereotipadas sobre la ingeniería (Chou y Chen, 2017; Diefes-Dux y Capobianco, 2011; Ergun y Balcin, 2019). En general, vinculan la ingeniería con actividades manuales de mantenimiento y construcción, más que con acciones intelectuales de diseño de procesos y productos para la solución de problemas o necesidades (Capobianco et al., 2011).

Sobre cómo se desarrolla la ingeniería, frecuentemente imaginan a las personas ingenieras en trabajo de campo y actuando de manera individual (Ata-Aktürk y Demircan, 2021; Ergun y Balcin, 2019; Fralick et al., 2009). Adicionalmente, presentan dificultades para entender la interdisciplinariedad entre la ingeniería y otras áreas, como las matemáticas y las ciencias (Thomas et al., 2020, 2016). Otro resultado recurrente en estas investigaciones es la identificación del sesgo de género, ya que tanto los niños como las niñas representan a las personas ingenieras mayoritariamente como hombres (Chou y Chen, 2017; Ergun y Balcin, 2019; Fralick et al., 2009).

Los estudios sobre las concepciones del alumnado acerca de la ingeniería están motivados por el creciente interés de esta área del conocimiento en las etapas preuniversitarias (Capobianco et al., 2011; Moore et al., 2014). Al respecto, se destacan los enfoques educativos STEM (interdisciplinariedad entre Ciencias, Tecnología, Ingeniería y Matemáticas) y STEAM (adicionalmente, considerando Artes/Humanidades) (Marín-Marín et al., 2021; Rodrigues-Silva y Álsina, in prensa). Entre otras transformaciones curriculares, estos enfoques educativos impulsan la inserción de la ingeniería en el currículo y su práctica desde la educación infantil (Cabello et al., 2021; Rodrigues-Silva y Alsina, 2023), siendo STEAM más amplio respecto a aspectos artísticos y humanísticos (Guyotte, 2020). España, por ejemplo, ha incluido la competencia STEM en el currículo de educación primaria para fomentar "*la comprensión del mundo utilizando los métodos científicos, el pensamiento y representación matemáticos, la tecnología y los métodos de la ingeniería para transformar el entorno de forma comprometida, responsable y sostenible*" (MEFP, 2022, p. 21).

Por un lado, desde la perspectiva de STEM y STEAM, el contacto temprano con la ingeniería es defendido como una forma de proporcionar contextos auténticos que integran otras áreas del conocimiento (Moore et al., 2014; Yakman y Lee, 2012). Asimismo, como estrategia para fomentar el interés de las chicas hacia la ingeniería (Sengupta-Irving y Vossoughi, 2019; Stephenson et al., 2021). En este contexto, se considera el Objetivo del Desarrollo Sostenible (ODS) referente a la disminución de la brecha de género existente en las carreras técnicas (Rodrigues-Silva y Alsina, 2023; United Nations, 2015). Por otro lado, se ha documentado que actividades STEM o STEAM mal diseñadas y gestionadas conducen o refuerzan concepciones equivocadas o estereotipadas sobre la ingeniería (Fleer, 2021; Matusovich et al., 2021). A modo de ejemplo, en el estudio de Fleer (2021) se evidencia que, en una actividad de construcción de puentes, las niñas evitaron usar materiales y herramientas propias del área de ingeniería, quedando estigmatizado que era algo de niños. En este sentido, diversas investigaciones señalan que estas concepciones estereotipadas dificultan la interdisciplinariedad y perpetúan los sesgos de género en la ingeniería (Fleer, 2021; Matusovich et al., 2021).

Para abordar esta problemática, Moore et al. (2014) proponen un modelo de enseñanza de la ingeniería a nivel preuniversitario donde se exploran conocimientos y habilidades de ingeniería mientras se desarrollan concepciones precisas sobre el área y la profesión de ingeniería. Considerando estos antecedentes, junto con la reciente inclusión de las competencias STEM en el currículo español (MEFP, 2022), se justifica explorar las concepciones del alumnado español sobre la ingeniería.

A partir de estos antecedentes, es posible plantear las hipótesis de que el alumnado de educación primaria de España, conforme los resultados de investigaciones realizadas en otros países, concibe la ingeniería como una profesión centrada en actividades manuales, realizadas desde un ambiente de trabajo de campo, de forma individual, con poca aplicación de conocimientos interdisciplinares (matemáticas y ciencias) y destinada a hombres. Con base en estas hipótesis, se ha diseñado un estudio cuyo objetivo es, tal como se presenta en este artículo, explorar las concepciones del alumnado de educación primaria de España acerca de la ingeniería en torno a cinco variables: 1) actividad, 2) lugar de trabajo, 3) forma de trabajo, 4) aplicación de conocimientos interdisciplinares (matemáticas y ciencias) y 5) género.

2. MARCO TEÓRICO

Los enfoques centrados en la interdisciplinariedad como STEM y STEAM integran la ingeniería en las distintas etapas escolares (Webb y LoFaro, 2020). Al respecto, Moore et al. (2014) proponen un modelo con indicadores claves de enseñanza de calidad de la ingeniería a lo largo de la escolaridad preuniversitaria. Siguiendo este modelo, a parte de los bloques de contenidos y habilidades de ingeniería (como el diseño de ingeniería), se destaca la necesidad de explorar y desarrollar las concepciones del alumnado sobre la profesión y el área de ingeniería.

Esta agenda de investigación es pertinente una vez que se ha observado que las actividades STEM y STEAM que no consideran las concepciones sobre la ingeniería pueden producir resultados indeseables sobre ellas (Fleer, 2021; Matusovich et al., 2021). Matusovich et al. (2021), por ejemplo, usaron el DAET antes y después de actividades de mantenimiento de linternas y de discusiones sobre coches y construcciones. Mediante el análisis de los dibujos del alumnado, los autores verificaron un aumento en la percepción de la ingeniería como una actividad manual (arreglar y construir), mientras que hubo una diminución de la concepción de la ingeniería desde procesos cognitivos como crear y diseñar. Además, observaron una reducción de respuestas que relacionasen la ingeniería con la resolución de problemas y con el uso interdisciplinar de conocimientos de otras áreas como matemáticas y ciencias. En esta misma línea, tal como se ha indicado anteriormente, una investigación sobre una propuesta STEM de construcción de puentes en educación infantil constató que las niñas evitaban el "área de ingeniería" donde estaban los materiales y herramientas necesarios para la actividad. La autora concluyó que la actividad refuerza en las niñas la concepción de que la ingeniería no es algo para ellas (Fleer, 2021).

En consecuencia, el desarrollo de actividades didácticas requiere claridad sobre las concepciones que el alumnado tiene sobre la ingeniería (Moore et al., 2014). En este sentido, Knight y Cunningham (2004) adaptaron para la ingeniería el test propuesto originalmente por Chambers (1983): Dibuje un Científico (*Draw a scientist Test* – DAST), hasta entonces usado para explorar las concepciones sobre los científicos.

A través del *Draw an Engineer Test* (DAET) se solicita a los participantes de las investigaciones que dibujen "personas que hacen ingeniería durante su trabajo" y, seguidamente, responden a ítems de aclaración sobre el dibujo (Knight y Cunningham, 2004). De acuerdo con Capobianco et al. (2011), este instrumento se basa, principalmente, en la teoría del pensamiento figurativo (Piaget y Inhelder, 1971) donde se argumenta que los dibujos (significante) representan sistemas personales de imágenes mentales sobre la ocupación de ingeniería (significado).

En las investigaciones que han aplicado el DAET se identifican algunos temas o categorías recurrentes acerca de las concepciones del alumnado en torno al profesional y al área de ingeniería. Por ejemplo, respecto a la actividad (Knight y Cunningham, 2004; Matusovich et al., 2021), el lugar y la forma de trabajo (Ata-Aktürk y Demircan, 2021; Ergun y Balcin, 2019; Fralick et al., 2009), la aplicación de conocimientos interdisciplinares (Thomas et al., 2020, 2016) y la representación de género (Chou y Chen, 2017; López et al., 2013), razón por la cual estos temas recurrentes configuran las hipótesis planteadas y las variables de este estudio.

Respecto a la actividad de ingeniería, se ha observado que el alumnado suele imaginar a la ingeniería como una profesión de manualidad (Capobianco et al., 2011; Ladachart et al., 2020). Ata-Aktürk y Demircan (2021), por ejemplo, reportaron que el alumnado mayoritariamente representó personas que físicamente ejecutan actividades de producción de artefactos (construcciones civiles y máquinas). En contrapartida, solo un 5% de ellos representó a profesionales de ingeniería desarrollando actividades de diseño. También a partir del DAET, Carr y Diefes-Dux (2012) identificaron que el alumnado estadunidense de educación primaria suele confundir a las personas ingenieras como mecánicos de automóviles, obreros de construcción civil u operadores de máquinas. Estos autores hicieron una segunda aplicación del instrumento en una muestra de 173 participantes para verificar el efecto de prácticas pedagógicas centradas en la ingeniería, evidenciándose un aumento de 5 para 80 en la cantidad de estudiantes que concebían la ingeniería como una actividad de diseño.

El lugar de trabajo es otro tópico frecuentemente observado en los estudios que han aplicado el DAET. Chou y Chen (2017), por ejemplo, observaron que el 73% del alumnado dibujó los profesionales de ingeniería trabajando en ambientes externos. De modo similar, Ata-Aktürk y Demircan (2021) verificaron que en 87% de los dibujos en que se pudo diferenciar el lugar de trabajo se configuraba como ambientes de trabajo de campo (en el exterior o en el subterráneo). De manera similar, otras investigaciones evidenciaron la predominancia de la representación del lugar en el que se lleva a cabo la profesión de ingeniería como trabajo de campo (Ergun y Balcin, 2019; Fralick et al., 2009).

En relación a la forma de trabajo, diversas investigaciones apuntan que más del 70% del alumnado representó a la persona que hace ingeniería trabajando individualmente (Ata-Aktürk y Demircan, 2021; Ergun y Balcin, 2019; Fralick et al., 2009). Este resultado es observado con cierta cautela ya que puede estar influenciado por la instrucción del DAET, que solicita al participante dibujar una persona que hace ingeniería. Sin embargo, a pesar de este posible sesgo, algunos estudios evidencian que hay una minoría del alumnado que representa a la persona ingeniería trabajando en colaboración (Ata-Aktürk y Demircan, 2021).

Thomas et al. (2020, 2016) crearon una versión del DAET que indaga sobre la integración de conocimientos entre la ingeniería y otras áreas, en particular matemáticas y ciencias. El análisis sobre la interdisciplinariedad es particularmente interesante en el contexto de la educación STEM o STEAM, pero también se hace pertinente como complemento a la exploración de la actividad de ingeniería (manual o intelectual). La escasa concepción acerca de la integración de áreas de conocimiento con la ingeniería puede relacionarse con la falta de reconocimiento del trabajo intelectual que conlleva la ingeniería. En este sentido, Matusovich et al. (2021) han puesto de manifiesto que la implementación de propuestas pedagógicas de mantenimiento y discusiones sobre construcciones han resultado en un aumento de la concepción de la ingeniería como actividad manual, junto con una disminución de la percepción sobre el papel de la matemática y la ciencia en la ingeniaría.

Finalmente, algunas investigaciones han evidenciado la existencia de sesgo de género en la imagen que el alumnado tiene sobre la persona que hace ingeniería. Por un lado, algunos autores han considerado rasgos como la vestimenta, la longitud del pelo, la forma del cuerpo o el uso de maquillaje como elementos identificadores de género (López et al., 2013; Matusovich et al., 2021). Por otro lado, algunos autores han usado estrategias como solicitar un nombre para la persona dibujada (Ergun y Balcin, 2019) o directamente preguntando al alumnado sobre el género que tuvo la intención de representar (Capobianco et al., 2011). Los resultados respecto a este tópico indican que, cuando se comparan niños y niñas, éstas últimas suelen representar proporcionalmente más a mujeres ingenieras (Capobianco et al., 2011). Sin embargo, tanto niños como niñas dibujan más a la persona que hace ingeniería como hombre (Chou y Chen, 2017; Ergun y Balcin, 2019; Fralick et al., 2009). Fralick et al. (2009), por ejemplo, observaron que un 87% de los participantes (niños y niñas) habían representado ingenieros hombres. Capobianco et al. (2011) evidenciaron que el alumnado, desde muy joven, ya muestra sesgo de género en la concepción de ingeniería. En concreto, estos autores observaron que, en el primer curso de primaria, la cantidad de dibujos representando hombres era el doble que el de mujeres. Además, concluyeron que el estereotipo de género se intensifica en años siguientes, si no se desarrollan estrategias dedicadas a revertir esta tendencia.

3. METODOLOGÍA

Se ha desarrollado un estudio exploratorio de tipo descriptivo, lo cual es recomendado para temas aún pocos estudiados (Mcmillan y Schumacher, 2005). Para llevar a cabo la investigación, se ha adoptado una metodología mixta donde se complementan los abordajes cualitativo y cuantitativo para proporcionar un entendimiento más amplio y profundizado del objeto de estudio (Creswell y Plano Clark, 2017).

3.1. Hipótesis

A partir de los tópicos identificados en la literatura, ha sido posible establecer cinco hipótesis de estudio. En concreto, se plantea que el alumnado español de una clase de quinto año de educación primaria concibe que la ingeniería:

- **H1:** se centra en actividades manuales;
- **H2:** se desarrolla desde un ambiente de trabajo de campo;
- **H3:** se desarrolla de forma individual;
- **H4:** utiliza pocos conocimientos interdisciplinares (matemáticas y ciencias);
- **H5:** se destina a hombres.

3.2. Muestra

La muestra está compuesta por 18 estudiantes de quinto curso de educación primaria (10-11 años): 6 niñas y 12 niños, con un promedio de edad de 10 años y 5 meses (desviación estándar de 6 meses). En cuanto a la selección de los participantes en el estudio, ha sido intencionada según la facilidad de acceso. El alumnado participa voluntariamente en el estudio y, además, cuentan con la autorización de sus progenitores o tutores, mediante la firma de un consentimiento informado. Para la garantía de anonimato, el alumnado ha sido codificado (EST01 a EST18).

La escuela seleccionada es pública y está ubicada en un entorno social y cultural medio de Girona (España), una ciudad de 100000 habitantes. Esta escuela indica, en su página web, que el proyecto educativo institucional tiene foco en la educación artística, la ciencia experimental, la enseñanza plurilingüe y la integración de las tecnologías de manera transversal.

La dirección de la escuela indicó que, según pruebas aplicadas institucionalmente, el nivel medio de la clase respecto a la comprensión lectora es un 6 sobre 10, mientras que el nivel medio en la prueba de matemáticas (que engloba resolución de problemas, razonamiento lógico, conectar ideas en otros contextos, comunicación y representación), es un 7 sobre 10.

3.3. Instrumento de recogida de datos

Como instrumento de recogida de datos se ha utilizado la traducción al español del *modified Draw an Engineer Test* – mDAET de Thomas et al. (2020). Este instrumento tiene una primera hoja con dos instrucciones: "Dibuje una persona que hace ingeniería durante su trabajo" y "Añada un globo de diálogo al dibujo explicando qué está diciendo o pensando esta persona". En esta parte, hay un recuadro en blanco para que se realice el dibujo.

Cuando el dibujo está finalizado, se entrega una segunda hoja en la que se plantean ítems de aclaración sobre el dibujo:

- Describe el trabajo de ingeniería.
- ¿Dónde está trabajando esta persona?
- ¿Cómo esta persona está usando matemáticas?
- ¿Cómo esta persona está usando ciencias?
- En tu dibujo representaste: a) mujeres, b) hombres, c) hombres y mujeres, d) ningún género.

3.4. Análisis de datos

En la Tabla 1, considerando las hipótesis planteadas, se listan en el mismo orden las variables de estudio en torno a las concepciones acerca de la ingeniería con una breve explicación. Para establecer los niveles de cada variable y la descripción de cada nivel, se ha refinado la rúbrica de análisis del mDAET (Thomas et al., 2016), que inicialmente estaba focalizada en las variables ordinales *actividad* y *conocimientos* *interdisciplinares*. En nuestro caso, la variable *conocimientos interdisciplinares* ha sido doblemente abordada, primero respecto a ciencias y luego a matemáticas. Las variables *lugar de trabajo*, *forma de trabajo* y *género* son de tipo categóricas y han sido analizadas según los niveles obtenidos de la literatura (Ergun y Balcin, 2019; Fralick et al., 2009) y adaptados conforme se explica a continuación.

Tabla 1. Concepciones sobre la profesión y la persona ingeniera.

Variable	Nivel	Descripción
Actividad: Comprensión sobre el tipo de trabajo de ingeniería.	0 - Actividad equivocada	La actividad pertenece a otras profesiones.
	1 - Actividad estereotipada	La actividad se relaciona con la ingeniería, pero desde tareas manuales.
	2 - Campos de la ingeniería o diseño	La actividad pertenece a algún campo específico de la ingeniería o está asociada a tareas de diseño, pero sin indicarla como solución a un problema o necesidad.
	3 - Diseño para solucionar problemas	La actividad implica tarea intelectual, como diseño para la solución de problemas o necesidades.
Lugar de trabajo: Comprensión sobre el lugar de trabajo de la ingeniería.	De despacho	El ambiente está más relacionado a despacho o laboratorio (interno).
	De campo	El ambiente está más relacionado al trabajo de campo (externo) como una construcción civil o área de producción de una fábrica.
Forma de trabajo: Compresión de la ingeniería como una actividad social.	Individual	Dibujan una persona.
	Colectiva	Dibujan más personas.
Conocimientos interdisciplinares: Comprensión sobre la	0 - No hace referencia	No hacen alusión al uso de la disciplina junto a la ingeniería, o bien indican que no se aplica.

interdisciplinariedad de la ingeniería con matemáticas o ciencias.	1 - Referencia simplista o descontextualizada	Mencionan habilidades de nivel básico, o bien indican conceptos sin contextualizar con la ingeniería.
	2 - Referencia contextualizada a la ingeniería	Asocian y justifican el uso de la disciplina dentro de un contexto de ingeniería.
Género: Imagen sobre el género de la persona que hace ingeniería.	Mujeres Hombres Ambos Ningún género	Se considera directamente la respuesta del alumnado en el ítem de aclaración sobre los géneros representados en el dibujo.

* La variable *conocimientos interdisciplinares* es abordada doblemente, primero respecto a ciencias y luego a matemáticas.

Se resalta que el análisis ha considerado la naturaleza cualitativa de los datos obtenidos a partir del instrumento mDAET. Así, se ha realizado un análisis cualitativo de las respuestas de forma integrada: dibujo, globo de texto e ítems de aclaración. Se ha procedido con una primera lectura de familiarización, seguida de lecturas en profundidad y múltiples comparaciones de los datos. Este análisis cualitativo complementa el abordaje cuantitativo con evidencias e informaciones relevantes además de ayudar a refinar los niveles de las variables.

La variable *lugar de* trabajo, por ejemplo, ha implicado en algunas dificultades de análisis. Inicialmente, se han considerado los niveles interior y exterior, de acuerdo con otros autores (Ata-Aktürk y Demircan, 2021; Ergun y Balcin, 2019; Fralick et al., 2009). Sin embargo, esto ha generado dudas y desacuerdos en varias ocasiones: un taller de coche, por ejemplo, podría ser interpretado como un ambiente interior o exterior; asimismo, hubo confusión para interpretar una persona que está en la línea de producción de una fábrica. Frente a esta dificultad, se prefirió definir el ambiente respecto a si es más como trabajo de despacho o trabajo de campo. De esta forma, esta variable ayuda a determinar si el ambiente representado está relacionado al desarrollo de actividades intelectuales o manuales.

Una vez cuantificada la frecuencia de los niveles de las variables, fueron analizadas con estadística descriptiva y una prueba de bondad de ajuste de chi-cuadrado para verificar posibles diferencias de frecuencia entre los niveles. Para eso, se ha adoptado un nivel de significancia de 0,05 para el testeo de hipótesis.

Seguidamente, se han aplicado pruebas de W*ilcoxon-Mann-Whitney* de dos colas y un nivel de significancia de 0,05 para comparar posibles diferencias entre niños y niñas en relación a la concepción sobre la *actividad* y *conocimientos interdisciplinares* (matemáticas y ciencias). En este caso, la prueba no paramétrica es más indicada para variables ordinales (Lawson et al., 2019; Wilcoxon, 1945). Adicionalmente, las áreas de matemáticas y ciencias fueron tomadas como dos condiciones distintas para la misma variable *conocimientos interdisciplinares*. De esta forma, se realiza una prueba *Wilcoxon Signed Rank* de dos colas y bajo un nivel de significancia de 0,05 para comparar la diferencia entre las dos condiciones (Lawson et al., 2019): uso de las matemáticas y uso de las ciencias en la ingeniería.

En este punto, es preciso aclarar que no se ha usado la rúbrica del mDAET para analizar la variable *género*. Este instrumento establece esta variable también como ordinal, indicando grados de estereotipo de género (Thomas et al., 2016). Contrariamente, se ha considerado que, en el contexto del test, un estereotipo de género no puede ser establecido a partir de un individuo y una única producción, sino desde un análisis de tendencias del conjunto de individuos o de múltiples producciones de un individuo. Se resalta también la no aplicación de estereotipos como el tipo de vestimenta, pendientes, maquillaje, para identificar los géneros representados. En este caso, la variable *género* fue cuantificada directamente según las categorías de género que el alumnado seleccionó en el ítem específico de aclaración sobre los dibujos.

4. RESULTADOS

A continuación, se presentan los resultados siguiendo el orden de las hipótesis/variables. Además, se complementa el análisis con ejemplos de evidencias cualitativas de las distintas variables y niveles.

4.1. La actividad, forma y lugar del trabajo de ingeniería

En la Figura 1 se presenta la distribución de frecuencia para los niveles de la variable *actividad*. Para este análisis, se ha aplicado una prueba de bondad de ajuste de chi-cuadrado. El test indica que las diferencias de frecuencia entre los niveles son significativas ($\chi^2_{(3)}$ = 9,56; p = **,023**). Esto no expresa que todos los niveles son diferentes entre sí, pero manifiesta que al menos un nivel se diferencia lo suficiente de los demás para que el resultado no sea considerado, con una confiabilidad de 95%, un mero efecto del azar. De esta forma, se puede observar que el nivel de actividades estereotipadas (Nivel 1) se destaca con elevada frecuencia (10) en relación a los demás niveles.

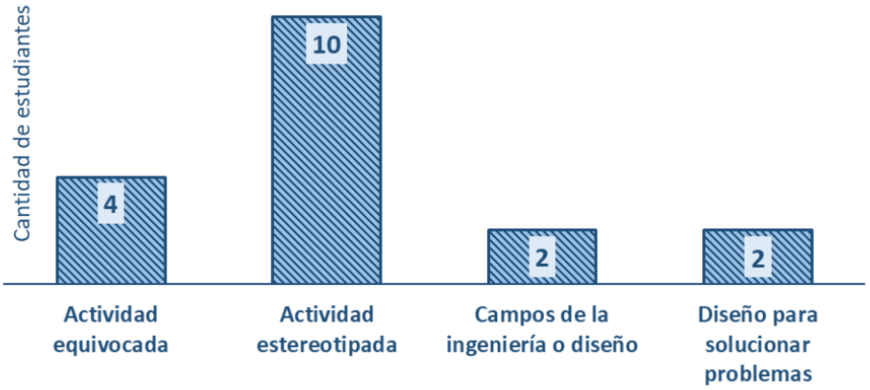

Fig. 1. Comprensión de la actividad de la ingeniería.

Además, se observa que cuatro de los participantes indicaron actividades equivocadas. Estos resultados nos indican que la mayoría del alumnado tiene algún conocimiento relacionado a la ingeniería. Al mismo tiempo, se constata que pocos tienen un conocimiento avanzado sobre la actividad de ingeniería, ya que únicamente dos de ellos perciben la ingeniería como una actividad de diseño y relacionada a la solución de problemas y de necesidades.

Asimismo, la aplicación de la prueba de *Wilcoxon-Mann-Whitney* de dos colas ha revelado que no hay evidencias desde una confiabilidad de 95% para diferenciar la comprensión de actividad de ingeniería entre niños y niñas ($U = 28$; $p = ,41$). Esto permite expresar que el alumnado posiblemente presenta un grado similar de comprensión sobre la actividad de ingeniería independiente de su sexo.

Con respecto a la actividad equivocada (Nivel 0), algunos estudiantes comprenden la ingeniería como profesiones y oficios tales como bomberos, jardineros, médicos o enfermeros. Para evidenciar este dato, en la Figura 2 se aprecian tres representaciones de ideas equivocadas sobre la actividad ingeniería. En la primera imagen se observa un bombero y un globo de diálogo que muestra un edificio en incendio (Est.05); en la imagen del medio se representa un jardinero que dice "me gusta mucho mi trabajo" (Est.06) y en la última imagen hay un médico que dice "estoy haciendo medicina" (Est.08).

Fig. 2. Comprensión de la ingeniería como actividades equivocadas.

En relación a actividad estereotipada (Nivel 1), se evidencia la representación de objetos relacionados al universo de la ingeniería como herramientas de construcción o mantenimiento: martillo, llaves, tornillos, tuercas. Al mismo tiempo, se observa la conceptualización de la persona que hace ingeniería desde el estereotipo de tareas manuales, más próximas a actividades de obreros de construcciones o mecánicos de automóviles, por ejemplo.

En consideración a campos de la ingeniería o diseño (Nivel 2), se evidencia que dos estudiantes alcanzan esta valoración. A modo de ejemplo, un alumno reconoce la existencia de diversos campos de la ingeniería "hay muchos tipos de ingeniería. Hay nuclear, atómica…" (Est.04). Aún respecto a este nivel, como se observa en la imagen izquierda de la Figura 3, una niña dibujó una mujer delante de una tostadora que dice "He [h]echo una tostadora" (Est.01). Aisladamente, el dibujo podría más bien indicar una concepción de ingeniería relacionada a manualidad y refiriéndose a la construcción de un objeto único (artesanía, *crafting*). Sin embargo, como se puede apreciar en la imagen derecha de esta misma figura, la respuesta al ítem de aclaración sobre el trabajo de ingeniería, "[p]ues de inventar cosas" (Est.01), evidencia la idea de creación/diseño del artefacto. Eso sí, la actividad de diseño representada no está acompañada de elementos que la vinculen a la solución de problemas o necesidades.

Fig. 3. Comprensión de la ingeniería como diseño.

Por último, en referencia a diseño para solucionar problemas (Nivel 3), también se han identificado sólo dos dibujos. Un niño presenta una comprensión elevada sobre la ingeniería al escribir “creo que la ingeniería son personas que hacen cosas a un material mejores de lo que son y también inventan cosas” (Est.03). Esta frase transmite su concepción de que la ingeniería, por una parte, busca diseñar nuevos productos y, por otra parte, optimizar los productos que ya existen.

Otro niño tuvo una comprensión elevada sobre la actividad de ingeniería, tal como se observa en la imagen de la izquierda de la Figura 4. Él ha representado un cohete de la NASA y una persona cuyo globo de diálogo expresa “si hay algún error podría costar la vida de mucha gente”. En la imagen derecha de esta misma figura, el alumno describe esta persona como un ingeniero aeroespacial de la NASA y especifica la labor de “revisar el cohete y hacer cálculos para que nadie salga herido” (Est.18). En este caso, se destaca que el niño visualiza la responsabilidad del trabajo de estos profesionales sobre la vida de los demás.

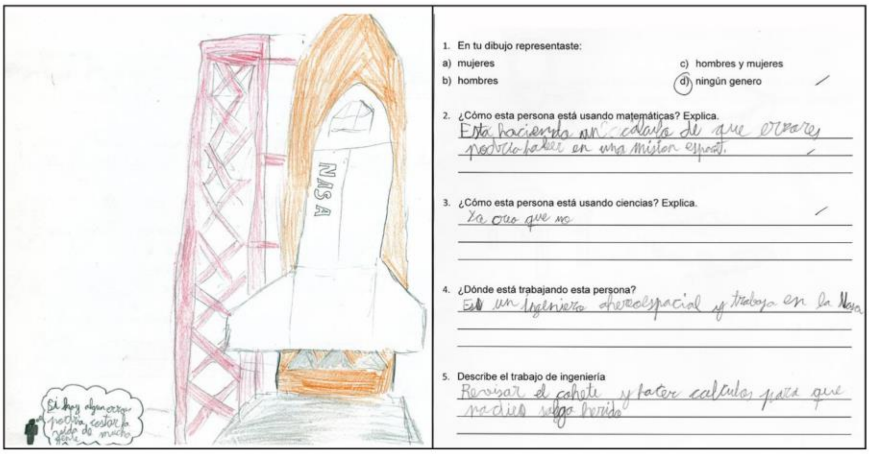

Fig. 4. Comprensión de la ingeniería como diseño para solucionar problemas.

En la Figura 5, presentamos juntas las variables *forma* y *lugar de trabajo*. Respecto a la forma de trabajo, 16 estudiantes representaron una persona trabajando de manera individual, mientras que únicamente dos participantes representaron más personas, de forma colectiva. Una prueba de bondad de ajuste de chi-cuadrado evidencia que esta diferencia es significativa ($\chi^2_{(1)} = 10{,}9$; p = **,001**).

A la derecha de la misma figura, se presenta que cinco escolares dibujaron lugares de trabajo que pudieron ser identificados como ambiente de despacho, en contraste a 12 de ellos que se clasifican más bien como ambiente de campo (exterior/ejecución). Aunque cualitativamente esta diferencia parece ser grande, considerando el tamaño de la muestra y solo dos niveles de comparación, la prueba de bondad de ajuste de chi-cuadrado no ha indicado diferencia estadísticamente significativa para esta variable ($\chi^2_{(1)} = 2{,}88$; p = ,090). Además, se aclara que en una respuesta se ha representado a una persona que posiciona un cubo preguntándose sobre la necesidad de ponerle tornillo. Ni el dibujo ni los ítems de aclaración aportaron informaciones que pudiesen identificar el lugar donde se desarrolla esta acción.

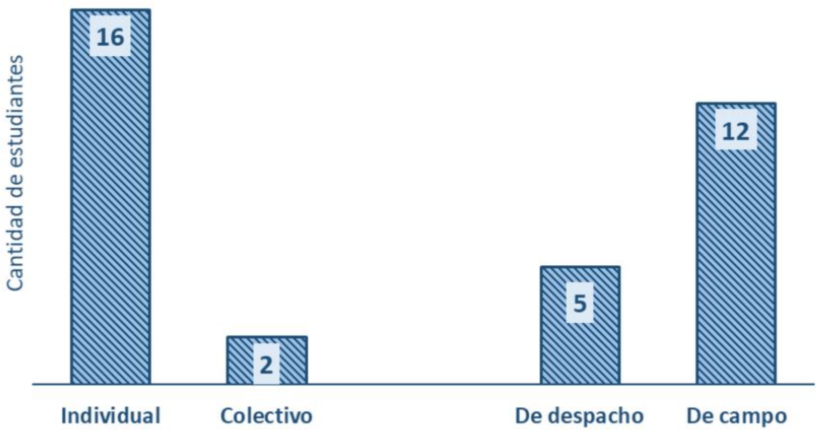

Fig. 5. Percepción sobre la forma de trabajo (individual o colectivo) y el lugar de trabajo (ambiente de despacho o de campo).

4.2. Conocimientos interdisciplinares

La variable *conocimientos interdisciplinares* ha sido analizada según dos condiciones: uso de las matemáticas y uso de las ciencias en la ingeniería. En la Figura 6, se presenta la distribución de frecuencia de los niveles de esa variable para la condición uso de matemáticas. Una prueba de bondad de ajuste de chi-cuadrado indica que las diferencias entre los niveles de comprensión sobre el uso de las matemáticas son significativas ($\chi^2_{(2)}$ = 12,3; p = **,002**). Nuevamente, revelando que al menos uno de los niveles si diferencia de los demás. Sin embargo, test U de *Wilcoxon-Mann-Whitney* de dos colas no indica evidencias suficientes para afirmar con una confiabilidad de 95% diferencias entre niños y niñas en cuanto a esta variable y condición (U = 33; p = 0,72). Esto nos permite afirmar que la mayoría de los participantes, 13 en total, hicieron una referencia simplista o descontextualizada del uso de las matemáticas en la ingeniería (Nivel 1). Mientras tanto, sólo dos estudiantes presentaron una referencia de esa disciplina de manera contextualizada a la ingeniería (Nivel 2).

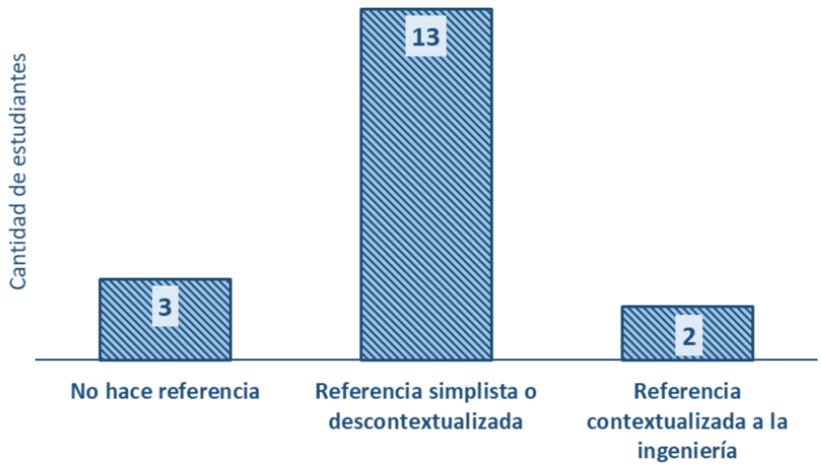

Fig. 6. Conocimientos interdisciplinares: uso de las matemáticas en la ingeniería.

Las respuestas del alumnado en los ítems de aclaración evidencian el nivel referencia simplista o descontextualizada respecto al uso de la matemática (Nivel 1). Mencionan habilidades matemáticas básicas como contar, medir longitud, medir masa, calcular cantidades, ubicar y unir. Por ejemplo, algunos estudiantes indican que en su dibujo la persona "está usando la matemática para medir…" (Est.01); "para calcular cuánto tiempo le queda para apagar el incendio" (Est.05); "para saber cómo arreglar el coche" (Est.11) y "vender, las matemáticas son necesarias para vender" (Est13). Por el contrario, sólo uno de los estudiantes identifica que la matemática se usa para solucionar un problema que ayuda a la sociedad: "Está haciendo un cálculo de que errores podría haber en una misión espacial… hacer cálculos para que nadie salga herido" (Est.18).

En la Figura 7 se presenta la distribución de frecuencia de niveles de la variable *conocimientos interdisciplinares* para la condición uso de las ciencias en la ingeniería. Una prueba de bondad de ajuste de chi-cuadrado indica que las diferencias entre los niveles de esta variable son significativas ($\chi^2_{(2)}$ = 12,0; p = **,002**). Posteriormente, la prueba U de *Wilcoxon-Mann-Whitney* de dos colas no evidenció, desde una confiabilidad de 95%, diferencias entre niños y niñas respecto esta condición (U = 27; p = 0,30). De esta forma, se puede afirmar, pero sin distinción de sexo, que más estudiantes (12) no hicieron ninguna referencia al uso de las ciencias por parte de la persona que hace ingeniería (Nivel 0). Apenas seis participantes alcanzan el nivel referencias simplistas o descontextualizadas (Nivel 1) y ningún estudiante logra realizar una referencia de la ciencia contextualizada a la ingeniería (Nivel 2).

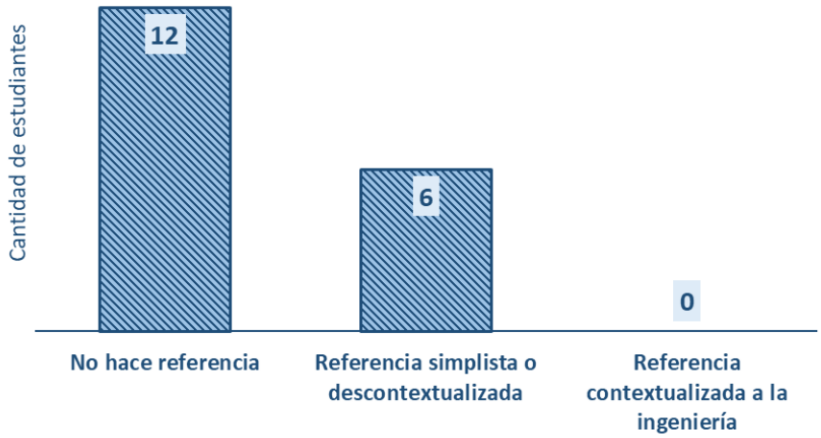

Fig. 7. Conocimientos interdisciplinares: uso de las ciencias en la ingeniería.

Por último, se ha aplicado la prueba *Wilcoxon Signed Rank* entre las dos condiciones de la variable conocimientos interdisciplinares: matemática y ciencias. Se ha verificado que existe una diferencia estadísticamente significativa entre ellas ($Z = -2,52$; $p=$ **,012**). Este hallazgo comprueba que la mayoría de los niños y niñas de esta investigación mostraron más percepción de la aplicación de la matemática que de las ciencias en la ingeniería. De un modo general, el alumnado presenta baja percepción del uso de conocimientos interdisciplinares en la ingeniería (matemáticas y ciencias).

4.3. Género

En la Figura 8 se observa que la representación de género ha sido bastante equilibrada entre las categorías mujeres, hombres y ningún género. De hecho, una prueba de bondad de ajuste de chi-cuadrado no indica evidencia diferencia de frecuencia entre estas categorías ($\chi^2_{(2)} = 1,33$; $p = ,51$). Este resultado cuantitativo significa que no es posible concluir que hay algún sesgo de género a partir de un análisis general de la clase. La cantidad de dibujos representando a hombres (8) fue muy similar de mujeres (6), por ejemplo.

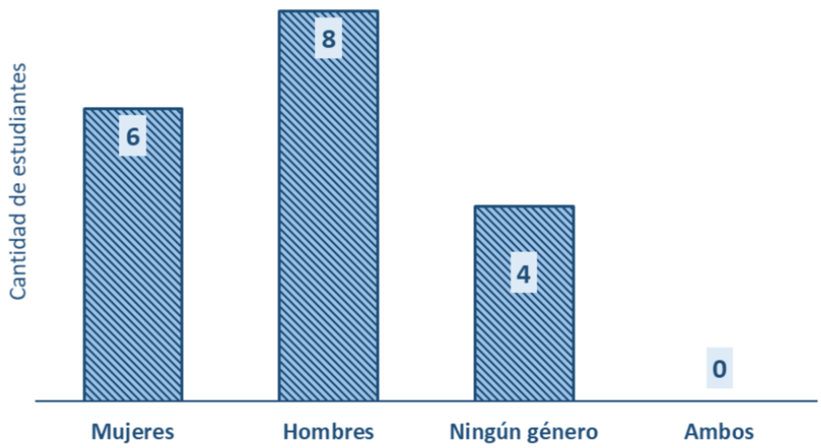

Fig. 8. Representación de género.

A continuación, se compara la dimensión representación de género según el sexo de los estudiantes. Como se puede observar en la Tabla 2, ninguna niña ha representado hombres en sus dibujos. En cambio, aproximadamente el 70% de los niños representaron hombres en sus dibujos. A pesar de que es un resultado dispar entre niños y niñas, se aclara que no se ha aplicado una prueba de chi-cuadrado para verificar si tal diferencia es estadísticamente significativa. Una prueba de chi-cuadrado exigiría un recorte dicotómico (por ejemplo, desconsiderando la categoría *Ningún género*) que reduciría demasiado la muestra (Lawson et al., 2019).

Tabla 2. Distribución de representación de género en los dibujos según el sexo de los participantes.

	Representación de género			
	Mujer	**Hombre**	**Ningún género**	**Total**
Niña	4	0	2	6
Niño	2	8	2	12
Total	6	8	4	18

Paralelamente, es posible observar que los niños, a pesar de dibujar mayoritariamente hombres, también realizan dibujos de mujeres o imágenes sin género. Por ejemplo, en la primera imagen de la Figura 9, una niña dibuja una ingeniera que trabaja en mecánica, donde se lee "es hora de trabajar de mecánica" (Est.11); en la imagen central, un niño ha dibujado mujeres que trabajan en construcción, donde se lee "el toldo es un poco más grande" (Est.17); en la última imagen, un niño representa una persona identificado por él como sin género, en el globo de texto expresa: "Está guay este trabajo, pero el director es muy severo… uf, cuánto dinero falta por contar" (Est.14).

Fig. 9. Representación de mujeres en ingeniería y personas sin género.

5. CONSIDERACIONES FINALES

En este estudio se han explorado las concepciones de 18 estudiantes españoles de educación primaria (10-11 años) sobre la ingeniería. Para ello, primero se han identificado temas recurrentes de la literatura que permitieron plantear las hipótesis de que el alumnado de educación primaria de este país podría concebir a la ingeniería como una profesión centrada en actividades manuales, desde un ambiente de trabajo de campo, realizada de forma individual, con poca aplicación de conocimientos interdisciplinares (matemáticas y ciencias) y destinada a hombres. A continuación, estas hipótesis se vieron reflejadas en cinco variables: 1) actividad, 2) lugar de trabajo, 3) forma de trabajo, 4) aplicación de conocimientos interdisciplinares (matemáticas y ciencias) y 5) género.

Respecto a la variable *actividad de ingeniería*, aproximadamente el 80% del alumnado representa esta profesión desde actividades equivocadas o estereotipadas. De este modo, se ha confirmado la hipótesis de percepción de la ingeniería desde actividades manuales. El análisis de los dibujos ha evidencido, por ejemplo, que el alumnado suele representar a obreros de construcción y mecánicos de automóviles. Este resultado es similar a las conclusiones de investigaciones realizadas anteriormente (Capobianco et al., 2011; Carr y Diefes-Dux, 2012; Knight y Cunningham, 2004).

En relación al *lugar de trabajo*, se ha observado que más del doble de los participantes han representado el lugar donde se desarrolla la ingeniería como un ambiente de trabajo de campo (12) en comparación a un ambiente de trabajo de despacho (5). Esta diferencia no es estadísticamente suficiente para confirmar esta hipótesis, sin embargo, la tendencia presentada es coherente con resultados obtenidos por otros autores (Ata-Aktürk y Demircan, 2021; Ergun y Balcin, 2019; Fralick et al., 2009).

Respecto a la variable *forma de trabajo*, se ha confirmado la hipótesis de que el alumnado concibe la ingeniería como un trabajo realizado individualmente. Aproximadamente 90% de los dibujos han representado solo una persona. Este resultado igualmente está alineado con hallazgos reportados en la literatura (Ata-Aktürk y Demircan, 2021; Ergun y Balcin).

En este punto, es pertinente aclarar que las personas ingenieras suelen intercalar ambientes de trabajo de campo (en la fábrica, construcción) con trabajo de despacho (laboratorios de informática). Es crítica la concepción de que este profesional está más en ambientes de trabajo de campo porque corrobora la idea de ejecución de actividades más manuales. De modo similar, aunque menos frecuente, hay ingenieros e ingenieras que realizan actividades de forma individual. Sin embargo, esa idea complementa la conclusión de la falta de entendimiento de la ingeniería como una actividad intelectual que demanda la participación de diversos profesionales para la actuación en proyectos complejos.

La siguiente hipótesis planteada se refiere a la dificultad que el alumnado tiene en visualizar la aplicación de *conocimientos interdisciplinares* (matemáticas y ciencias) en la ingeniería. Se ha confirmado esta hipótesis ya que aproximadamente el 70% del alumnado identifica el uso de las matemáticas en la ingeniería, pero de manera simplista o descontextualizada. Paralelamente, se ha verificado que dos tercios del alumnado no hacen referencia a la aplicación de las ciencias en la ingeniería. Al comparar las dos disciplinas, ha sido posible concluir que el uso de las ciencias fue estadísticamente menos evidente en la ingeniería que las matemáticas. Es pertinente resaltar que niñas y niños tuvieron concepciones similares respecto a la *actividad* y *conocimientos interdisciplinares* sobre la ingeniería. En esta misma línea, Thomas et al. (2016) también identificaron que la mayoría de los dibujos analizados, independiente del sexo del alumnado, tenían representaciones simplistas o descontextualizadas del uso de las matemáticas y de las ciencias en la ingeniería.

Finalmente, se ha observado que las niñas han dibujado más a mujeres ingenieras mientras que los niños han dibujado más a hombres. Al considerar el total la muestra de este estudio, no se ha verificado la hipótesis inicial de un sesgo de género porque las diferencias entre las categorías de representaciones de género no son estadísticamente significativas. Relativo a esta variable, se defiende la necesidad de trabajos futuros con muestras más amplias.

Se hace hincapié en la necesidad de abordar estas concepciones como punto de partida en la implementación de la ingeniería en la escuela (Moore et al., 2014). En específico, asumimos que solo de esta forma, la interdisciplinariedad cobra sentido para el alumnado desde el contexto de la educación STEAM. En este orden de ideas, para un país como España que ha incorporado el desarrollo de competencias interdisciplinares de ciencias, tecnología, ingeniería y matemáticas en su currículo (MEFP, 2022), será necesario poner atención en diversos aspectos. Por una parte, es necesario situar las concepciones que el alumnado tiene sobre la ingeniería como primer paso para el desarrollo del pensamiento acerca de la ingeniería y otras competencias STEAM. Por otra parte, se requiere avanzar en la formación del profesorado sobre la educación STEAM y en particular en la incorporación de la ingeniería en las primeras etapas escolares (Moore et al., 2014; Rodrigues-Silva y Alsina, 2022). Sobre este último punto, la literatura indica que el profesorado suele presentar desconocimiento y concepciones equivocadas sobre la ingeniería, muchas veces parecidas a las concepciones del alumnado (Ladachart et al., 2020; Vo y Hammack, 2022).

Una de las limitaciones de este estudio es que el tamaño de la muestra no permite generalizar los datos obtenidos a la población del alumnado de primaria de España. Sin embargo, ha permitido realizar una primera aproximación que pone de manifiesto las concepciones de un grupo de estudiantes de esta etapa educativa y, en consecuencia, señala algunos aspectos que deben seguir explorándose. De este modo, en el futuro será imprescindible diseñar estudios similares con muestras más amplias, junto con investigar las concepciones del profesorado sobre esta área del conocimiento.

Asimismo, será necesario diseñar y validar programas de formación que permitan incluir el enfoque STEAM en la educación inicial y continua del profesorado español, como una estrategia para el logro de los objetivos de su nuevo currículo. Esta formación deberá contemplar el desarrollo de una concepción no estereotipada de la ingeniería por parte de dicho profesorado. Así también, será relevante avanzar en investigaciones que sitúen el panorama de la ingeniería temprana en la escuela, además de ofrecer propuestas didácticas con las cuales el profesorado visualice las conexiones de la ingeniería con las matemáticas y las ciencias y con otras áreas STEAM.

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Students' conceptions of engineering and its connections with mathematics and science

The literature evidences that children from countries such as the United States, Turkey, Mexico, and China hold stereotypical conceptions of engineering. Generally, they conceive engineering as manual work conducted in field environments, carried out individually, with limited application of interdisciplinary knowledge (mathematics and science), and pursued by men. In the meantime, Spain has recently included STEM competencies (referring to the interdisciplinary teaching of Science, Technology, Engineering and Mathematics) in its primary education curriculum, notwithstanding students' conceptions of engineering are underexplored in this country. Accordingly, we sought to explore Spanish students' conceptions of engineering in primary school.

For that, we identified recurrent themes in the literature that allowed making hypotheses reflected in five variables: 1) activity, 2) place of work, 3) working setting, 4) application of interdisciplinary knowledge (mathematics and science) and 5) gender. Subsequently, we enrolled on mixed-method research applying the validated instrument Draw an Engineer Test (mDAET) to 18 students from the fifth year of primary school (10-11 years old) in Spain. Data were first analysed qualitatively by integrally considering the drawings, the text balloons and clarification items responses. This qualitative analysis was essential to refine the levels of the variables and provide qualitative evidence. Second, we quantified the frequency of the variable levels and ran different non-parametric statistical tests (considering the reliability of 95%) to compare differences within those levels and between girls and boys.

The results showed that approximately 80% of the pupils have a stereotypical conception of engineering as a manual activity (p = **.023**), 70% draw the engineering workplace as in the field (p = .090), 90% imagine the engineer working individually (p = **.001**). Furthermore, they have difficulty perceiving the interdisciplinary connections of mathematics and science with engineering: 70% of students identify the use of mathematics in engineering in a simplistic or decontextualised way (p = **.002**). Approximately 70% of the students do not consider the use of science in engineering (p = **.002**). This difference between the application of mathematics and science in engineering proved to be statistically significant (p= **.012**).

Overall, the gender picturing was reasonably balanced with no significant differences between female, male, and no gender categories ($p = .51$). Although girls drew female engineers, boys drew more male engineers; data was insufficient to determine gender differences. Moreover, we found no significant difference between boys' and girls' conceptions of engineering regarding any variable. In this sense, enlarging the sample in future studies will be necessary to check for gender differences.

In conclusion, most of the hypotheses have been confirmed. The participants presented stereotypical conceptions of engineering, viewing it primarily as manual activities conducted in fieldwork environments and pursued individually. Additionally, they exhibit a limited understanding of the role of mathematics and fail to recognise the integration of science in engineering. For a country such as Spain—that has incorporated interdisciplinary STEM competencies in its curriculum—designing and validating teacher training programmes centred on STEM or STEAM (also considering Arts/Humanities) education become crucial. Our results point out the necessity to advance investigations regarding the introduction of early engineering and provide didactic examples that help teachers visualise the connections between engineering, mathematics, science, and other STEAM areas. Moreover, those training and didactic proposals should aim to challenge and overcome the stereotypical conceptions of engineering.

Acceptance proof

ENSEÑANZA DE LAS
CIENCIAS
REVISTA DE INVESTIGACIÓN Y EXPERIENCIAS DIDÁCTICAS

Ángel Gutiérrez Rodríguez, como codirector de la Revista Enseñanza de las Ciencias,

C E R T I F I C O:

Que **Jefferson Rodrigues-Silva**, **Marcela Silva-Hormazábal** y **Ángel Alsina** han presentado el artículo cuyos datos figuran más abajo en la revista Enseñanza de las Ciencias. Dicho artículo ha sido aceptado para su publicación y será incluido en uno de los próximos números de la revista.

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Y para que conste a los efectos oportunos y a petición de la persona interesada, firmo el presente documento.

Valencia, 29 de mayo de 2023

ARTICLE 7

Effects of a practical teacher-training program on STEAM activity planning

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Effects of a practical teacher-training program on STEAM activity planning

Efeitos de um programa prático de formação de professores em planejamento de atividades STEAM

Efectos de un programa práctico de formación del profesorado en la planificación de actividades STEAM

Jefferson Rodrigues-Silva[1,2], Ángel Alsina[2]

[1] Federal Institute of Minas Gerais, Arcos, Minas Gerais, Brazil.
[2] University of Girona, Girona, Spain.

Corresponding author:
Jefferson Rodrigues-Silva
Email: jeffe.rodri@gmail.com

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ABSTRACT
We sought to analyse the effects of a practical teacher-training program on teachers' abilities in planning STEAM activities. For that, a case study is presented in a mixed-method research approach. 14 Brazilian teachers took part in a course wherein they received mentoring, instruments, and feedback to develop STEAM plans. In this research, data were collected from two surveys, from previously validated open-ended questions, and from the STEAM plans as final products. Quantitative data was analysed through nonparametric statistical tests, and qualitative data underwent content analysis according to the Ground Theory commandments. As a result, teachers reported a positive view of the STEAM impact and a high predisposition towards it. Although they considered merging STEAM areas challenging, especially Engineering and Technology, the training helped them surpass it. All plans had at least two areas, and half of them had all five STEAM areas. Around 70% of the teachers used an active learning teaching method which was new to them. There was a significant augment in teachers' self-efficacy in planning STEAM activities.
Keywords: Lesson planning. STEAM Education. Teacher professional development.

RESUMO
Analisaram-se os efeitos de um programa prático de formação docente no desenvolvimento de habilidades dos professores no planejamento de atividades STEAM. Para isso, apresenta-se um estudo de caso com uma abordagem de pesquisa de métodos mistos. 14 professores brasileiros participaram de um curso no qual receberam mentoria, ferramentas e feedback para desenvolver planos didáticos STEAM. Nesta pesquisa, foram coletados dados por meio de questionarios, de

perguntas abertas previamente validadas, e os planos STEAM como produtos finais. Os dados quantitativos foram analisados por meio de testes estatísticos não paramétricos e os dados qualitativos foram submetidos à análise de conteúdo de acordo com indicações da Teoria fundamentada. Como resultado, os professores relataram uma visão positiva sobre impacto de STEAM e uma alta predisposição em deenvolvê-lo. Apesar de considerarem integrar as áreas STEAM uma tarefa desafiadora, especialmente Engenharia e Tecnologia, o treinamento os ajudou a enfrentá-la. Todos os planejamentos tinham pelo menos duas áreas, e metade deles tinha todas as cinco áreas STEAM. Cerca de 70% dos professores utilizaram um método de ensino de aprendizagem ativa que era novo para eles. Houve um aumento significativo na autoeficácia dos professores no planejamento de atividades STEAM.
Palavras-chave: Desenvolvimento professional docente. Educação STEAM. Planejamento didático.

RESUMEN

Se analizan los efectos de un programa práctico de formación docente sobre el desarrollo de las habilidades del profesorado en la planificación de actividades STEAM. Para ello, se presenta un estudio de caso con un enfoque de investigación de método mixto. 14 profesores brasileños participaron de un curso en el cual recibieron mentoría, instrumentos y retroalimentación para desarrollar planes STEAM. En esta investigación se recolectaron datos de dos encuestas, de preguntas abiertas previamente validadas, y de los planes STEAM como productos finales. Los datos cuantitativos fueron analizados a través de pruebas estadísticas no paramétricas, y los datos cualitativos fueron sometidos a análisis de contenido de acuerdo con las indicaciones de la Teoría Fundamentada. Como resultado, los docentes informaron una visión positiva del impacto STEAM y una alta predisposición hacia ello. Si bien consideraron desafiante fusionar áreas STEAM, especialmente Ingeniería y Tecnología, la capacitación les ayudó a enfrentar esta dificultad. Todos los planes tenían al menos dos áreas, y la mitad de ellos tenían las cinco áreas STEAM. Alrededor del 70% de los profesores utilizaban un método de enseñanza de aprendizaje activo que era nuevo para ellos. Hubo un aumento significativo en la autoeficacia de los docentes en la planificación de actividades STEAM.
Palabras clave: Desarrollo professional docente. Educación STEAM. Planificación didactica.

INTRODUCTION

STEAM is an educational approach which argues for interdisciplinarity between Science, Technology, Engineering, Arts/Humanities, and Mathematics. This acronym emerged during the Americans for the Arts-National Policy Roundtable discussion in 2007 (Perignat & Katz-Buonincontro, 2019). Since then we observe excitement (Cook et al., 2020) and uninterrupted research about it (Getmanskaya, 2021; Marín-Marín et al., 2021). STEAM's main justification lies in the argument that, in a highly technological world, complex problems cannot be addressed by isolated knowledge (López et al., 2021; Quigley et al., 2017).

Most studies on STEAM are focused on students, curriculum, and assessment (Kartini & Widodo, 2020), whereas little research addresses STEAM teaching training programs (Kim & Bolger, 2017). Accordingly, a bibliometric analysis of performance and co-words in Web of Science confirms this gap. Findings showed teacher training is a recent thread on STEAM. And this research line became evident only from 2019 (Marín-Marín et al., 2021).

Besides being a new thread, researchers agree on the necessity of proper teacher training to ensure STEAM implementation in schools (Cook et al., 2020). In addition, studies suggest teachers without solid content knowledge and pedagogical skills associated with STEAM are likely to experience pedagogical discontentment during the attempt to implement it (Boice et al., 2021).

Some already existing research emerges on teachers' difficulties and needs for STEAM implementation. They also struggle to merge STEAM areas beyond simply adding those components together (Cook et al., 2020). For instance, Boice et al. (2021) observed teachers tend to teach content from their specific discipline, while only superficially contextualising its relation with other areas. Teachers are likely to focus on activities, neglect content knowledge, and plan assessments on performance or final products rather than evaluating the learning process (Cook et al., 2020). Furthermore, they lack familiarity with Engineering (Webb & LoFaro, 2020) and they are likely to reduce Technology from a proper knowledge area to the mere use of resources, such as digital devices (Cook et al., 2020).

Moreover, there is a significant mismatch between teachers' perceptions and actual practices of STEAM education (Park et al., 2016). Studies show teachers usually have a positive view and apparent support for STEAM (Kartini & Widodo, 2020; Park et al., 2016), although many of them actually resist implementing it in their classes (Park et al., 2016). Teachers have opinions and perhaps misconceptions about STEAM (Kartini & Widodo, 2020; Lee, 2021; Park et al., 2016), and those beliefs have a great influence on their teaching.

This panorama, where teachers may have misconceptions and struggle with implementing STEAM, encourages the search for an appropriate educational approach to teacher training on STEAM Education.

The literature already has a clue in this sense. Researchers found teachers prefer STEAM teacher training with practical features, such as case-centred, activity-centred, and field applications methods (Leroy & Romero, 2021). Accordingly, practical teacher training programs focused on STEAM planning have shown promising results (Boice et al., 2021; Cook et al., 2020; Kim & Bolger, 2017). It responds to teachers' needs since planning STEAM is challenging for them (Boice et al., 2021; Cook et al., 2020).

Cook et al. (2020), for example, reported a two-year practical teacher-training program on STEAM activity planning. Their results showed an increase in the alignment of the plans with quality standards, meaningful integration of STEAM knowledge areas, and use of formative assessment. After one year of training, Boice et al. (2021) observed teachers unanimously reported using STEAM in their classes at least sometimes.

Considering all that, a four-month practical teacher-training program on STEAM activity planning was enrolled in Brazil. During this formation, teachers shared their prior knowledge and beliefs about STEAM. Then, they received guidelines and templates for planning STEAM activities. In parallel, lessons and mentoring intended theoretical scaffolding on STEAM and active learning teaching methods. After two feedback sessions from the mentor teacher over their STEAM planning. Finally, teachers underwent peer and self-assessment processes using a rubric to verify STEAM plans alignment. The course ended with a reflection session about their learning.

Addressing the stated literature gap on STEAM teacher training, the following research questions are formulated:

RQ1. What are teachers' initial opinions related to STEAM Education?

RQ2. How did the teacher training program affect teachers' abilities on planning STEAM activities?

Responding to those questions, this research aims to analyze the effects of a practical teacher-training program on teachers' abilities in planning STEAM activities.

METHODOLOGY

The research has a mixed-method approach (Mcmillan & Schumacher, 2005). It is a case study about an online practical teacher-training program STEAM activity planning. This course was enrolled from May to August 2021 (four months duration) at the Federal Institute of Minas Gerais (IFMG), in Brazil. As previously indicated in the introduction, during this training teachers shared and discussed their beliefs about STEAM. Then, they received mentoring and instruments for planning STEAM activities. Table 1 details the four stages of the program and its corresponding processes.

Table 1. Stages and processes of the teacher-training program on planning STEAM activities

Month/year	Stage	Process
May/2021	Welcoming and preparation	Personal presentation Organization: guidelines, deadlines, templates Discussions on prior knowledge and beliefs about STEAM Theoretical scaffolding on STEAM and active learning methods
June/2021	Feedback – first round	Feedback centred on issues related to STEAM, teaching methods, learning objectives
July/2021	Feedback – second round	Feedback centred on issues related to STEAM planning (timing, assessment, etc.), and text body structure
August/2021	Finalization	Peer and self-assessment Final version Reflection on learning

20 teachers freely took part in the mentioned teacher training program, 14 of whom volunteered to be included in this research. Those teachers firmed a consent term. We highlight most teachers are from Humanities (10), some from science (3) and also from engineering (1). Additionally, there was a non-equilibrated gender distribution, with 11 female and 3 male participants. From now on, participants are simply referred to as teachers, and whenever necessary, we will code them as P01 until P14 for anonymity purposes.

Data was collected from different sources. At the beginning of the program, participants filled out a form regarding sample characterization (such information was already presented above). Simultaneously, we administered survey I, a Likert instrument (scale 1 to 5) organized into two main parts. Teachers' evaluation of 18 educational approaches was explored considering four dimensions: Knowledge, Usage, Willing to use, and Appropriateness to STEAM (part A). Teachers' opinions on STEAM Education impact, predisposition toward STEAM, self-efficacy in considering each STEAM area, and the general self-efficacy in planning STEAM activities (part B).

At the end of the program, the STEAM activity plans were collected as teachers' final product. Additionally, we administered survey II. This instrument was also organized into two parts: general self-efficacy in planning STEAM activities was repeated (part A). Open-ended questions about planning STEAM activities, from a more qualitative perspective (part B). Those open-ended questions were previously validated by Kim and Bolger (2017) during an investigation of a teacher training program on STEAM planning enrolled in Korea. In Table 2 we present a summary of data sources, themes, the quantity of questions/elements, and the analyses procedure.

Table 2. Data source and analysis

Data source		Theme	Quantity of questions/elements	Analysis
Form		Sample characterization	4 questions	Descriptive statistics
Survey I	Part A	Educational approaches	18 educational approaches x 4 dimensions	One way within-subject ANOVA Likert graphical representation Wilcoxon Signed Ranks test
	Part B	STEAM Education impact	15 elements	Descriptive statistics: percentile and Friedman test
		Predisposition towards STEAM	4 questions	Descriptive statistics: percentile and Friedman test
		Considering the STEAM areas	5 questions	Friedman test
		Self-efficacy in planning STEAM activities (first measure)	1 question	Used afterwards in a pre-post-test design
STEAM activity plan		Application of each STEAM area	14 STEAM activity plans	McNemar test
		Application of active learning teaching methods		Descriptive statistics
Survey II	Part A	Self-efficacy in planning STEAM activities (second measure)	1 question	Wilcoxon Signed Ranks test
	Part B	Open-ended questions	5 questions	Multiple comparisons on Ground Theory

18 educational approaches were aggregated into a single scale variable ranging between 18 and 90 (survey I, part A). This variable was repeatedly measured on different dimensions: Knowledge, Usage, Willing to use, and Appropriateness to STEAM. On the dimension of Knowledge, for example, the greater the value of this variable, the more teachers agree on knowing a large variety of educational approaches.

After this variable was created, we run a Friedman test. This nonparametric test was used to verify differences within subjects from one single sample, considering repeated measures on more than two different conditions (Lawson et al., 2019), the four mentioned dimensions, in our case. We preferred nonparametric tests throughout the research because of the small sample size or variable ordinal level measurement.

Specific observations (non aggregated) were done in this same part of the instrument, so each educational approach was treated as a variable (ordinal level). They were represented graphically on R Studio Statistics using the Likert library. Then multiple Wilcoxon signed-rank tests compared each educational approach considering only two dimensions at a time. Similarly to the Friedman test, Wilcoxon signed-rank test is used to verify differences within subjects from one single sample, only between two conditions though (Lawson et al., 2019). This test was used to verify differences in repeated measures regarding the four dimensions, two at a time.

In part B of survey I, we used descriptive statistics of a list of 15 possible positive STEAM impacts, and four items about predisposition towards STEAM. After, a Friedman test verified differences in teachers' self-efficacy in considering each STEAM knowledge area in the STEAM plans. The question about general self-efficacy in planning STEAM activities was reserved to be used afterwards in a pre-post-test design.

We analyzed the content of the STEAM plans teachers developed. For that, five binomial variables were created for each STEAM knowledge area (with levels: presence and absence). Then, the knowledge areas were accounted for as present/absent in the STEAM plans. This information was contrasted with teachers' self-efficacy in considering each one of those STEAM areas (data from survey I). These variables were also converted into binomial ones. For example, participants who had asserted efficacy in considering the knowledge area in the plan were accounted for the value "presence". After this preparation, a McNemmar Test was run to verify a significant change in teachers' initial self-efficacy in considering each STEAM knowledge area to its actual usage in the plans. This test was chosen because it permits verifying changes in paired binomial data (Pembury Smith & Ruxton, 2020).

Similarly, we analyzed the usage of active learning teaching methods in the STEAM plans. This information was crossed with teachers' prior use of that teaching method, as indicated in part A of the survey I in the dimension of Usage.

Finally, in part A of survey II, a Wilcoxon Signed Ranks Test was run in a pre-post-test to verify a change in self-efficacy in planning STEAM activities. Part B of this instrument was qualitative. In this part, open-ended questions were analysed through multiple comparisons, then categories were induced as established by Ground Theory (Strauss & Corbin, 1994). We did a first scan reading; then subsequent readings to draft and refine categories, by merging or splitting them whenever necessary. This process iterates until saturation is reached. Finally, we calculated the incidence frequency of each category, and we select representative answers which qualify them.

RESULTS

Results are organized in the same order as presented in the data analysis subtopic, and they sequentially address our research questions. Therefore, you are invited to read from this point with our first inquiry in mind - What are teachers' initial opinions related to STEAM Education?

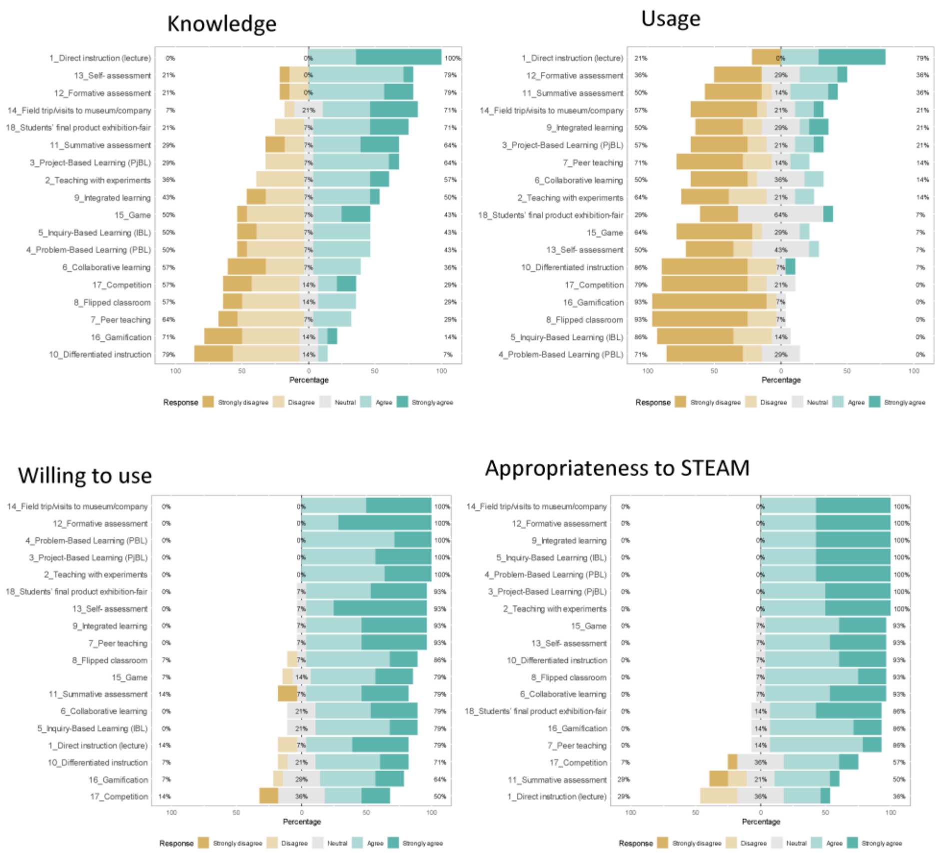
As previously explained in the data analysis topic, we aggregated data from 18 educational approaches into a single variable. This variable captures teachers' evaluation of the variety of those educational approaches. As result, the dimension of Usage had a mean rank of 1.07, followed by Knowledge, with a mean rank of 2.07. Willing to use and Appropriateness to STEAM had mean ranks of 3.32 and 3.34. A Friedman test indicated significant differences regarding those four dimensions ($\chi^2_{(14)}$ = 33.6, p = .001). In other words, teachers are willing to use and think a broader variety of educational approaches is Appropriate to STEAM, than they actually know and practice.

This data was further analyzed for more specific information. First, we addressed it through visual insight. For that, Figure 1 presents teachers' evaluation of the same 18 educational approaches regarding four dimensions: Knowledge, Usage Willing to use, and Appropriateness to STEAM. On the top of the graphs are positioned the most asserted educational approaches, and at the bottom are the approaches rated with more disagreement. Agreement, neutrality, and disagreement frequency percentages are shown on the right, middle and left sides respectively.

Visually, comparing the green areas of the graphs is possible to perceive teachers seem to have asserted more Knowledge than Usage. Results show agreement frequency on Knowledge superior to 70% on five educational approaches. In contrast, only direct instruction presents an agreement frequency superior to 70% in the dimension of Usage.

Regarding the dimensions of Willing to use and Appropriateness to STEAM, both graphs indicate a high tendency toward the agreement pole (green colour) for educational approaches. In fact, most educational approaches have an agreement frequency superior to 70% in the two dimensions.

Figure 1. Teachers' opinions about 18 educational approaches regarding the dimensions of Knowledge, Usage, Willing to use, and Appropriateness to STEAM.



Now considering only two conditions at a time. As shown in the first columns of Table 3, there was evidence Knowledge had a superior agreement rate compared to Usage in most educational approaches.

Table 3. Wilcoxon Signed-Rank test on 18 educational approaches regarding the dimensions Knowledge (K), Usage (U), Willing to use (W), and Appropriateness to STEAM (A).

Educational approach	K vs U		W vs A		K vs A		U vs A	
	Z	p value	Z	p value	Z	p value	Z	p value
Collaborative learning	- .97[b]	NS	-1.00[b]	NS	-3.09[b]	<.05	-3.21[b]	<.05
Competition	-2.40[b]	<.05	-.614[b]	NS	-1.48[b]	NS	-3.10[b]	<.05
Differentiated instruction	-1.25[b]	NS	-1.47[b]	NS	-3.37[b]	<.05	-3.25[b]	<.05
Direct instruction	-1.80[b]	NS	-2.75[c]	<.05	-3.02[c]	<.05	-1.35[c]	NS
Teaching with experiments	-2.68[b]	<.05	-.71[b]	NS	-2.46[b]	<.05	-3.37[b]	<.05
Flipped classroom	-3.07[b]	<.05	-.63[b]	NS	-2.97[b]	<.05	-3.41[b]	<.05
Field trip/visits to museum/company	-3.15[b]	<.05	-.45[b]	NS	-2.33[b]	<.05	-3.20[b]	<.05
Final product exhibition	-2.80[b]	<.05	.00[d]	NS	-1.45[b]	NS	-2.98[b]	<.05
Formative assessment	-2.97[b]	<.05	-.63[c]	NS	-2.41[b]	<.05	-2.95[b]	<.05
Game	-2.80[b]	<.05	-.90[b]	NS	-2.33[b]	<.05	-3.33[b]	<.05
Gamification	-2.91[b]	<.05	-1.00[b]	NS	-3.13[b]	<.05	-3.38[b]	<.05
Inquiry-Based Learning (IBL)	-2.88[b]	<.05	-2.00[b]	<.05	-2.96[b]	<.05	-3.40[b]	<.05
Integrated learning	-1.21[b]	NS	-.58[b]	NS	-2.68[b]	<.05	-2.92[b]	<.05
Problem-Based Learning (PBL)	-2.91[b]	<.05	-1.41[b]	NS	-2.96[b]	<.05	-3.35[b]	<.05
Peer teaching	-1.78[b]	NS	-1.90[c]	NS	-2.85[b]	<.05	-3.10[b]	<.05
Project-Based Learning (PjBL)	-3.07[b]	<.05	-.38[b]	NS	-2.72[b]	<.05	-3.08[b]	<.05
Self- assessment	-2.99[b]	<.05	-1.41[c]	NS	-2.07[b]	<.05	-3.11[b]	<.05
Summative assessment	-2.75[b]	<.05	-2.64[c]	<.05	-.72[c]	NS	-1.11[b]	NS

b. Based on positive ranks. c. Based on negative ranks. NS. Non-significant

We decided to present differences between Knowledge and Appropriateness to STEAM, and between Usage and Appropriateness to STEAM. The combinations Knowledge and Willing to use, and Usage and Willing to use were omitted because Wilcoxon Signed Rank tests indicated teachers evaluated Willing to use and Appropriateness to STEAM similarly.

Comparison of Knowledge and Appropriateness to STEAM shows most approaches presented significant differences. We highlight direct instruction was calculated based on negative ranks. According to the sequence in which the test was designed, that imply although teachers indicated they know, they don’t consider this educational approach so appropriate to STEAM.

Last, Wilcoxon Signed Rank tests were run regarding Usage and Appropriateness to STEAM. Most approaches show significant differences. They were calculated based on positive ranks. By the order of the test, it denotes teachers attributed higher rates to Appropriateness to STEAM than its Usage.

Teachers' opinion on STEAM Education's impact was evaluated through a list of 15 items. Table 4 list them in a rank order, starting from the most positively evaluated. We highlight the medians of all aspects lay in the values 4 (Agree) and 5 (Strongly agree). This result points to teachers’ overall positive evaluation of STEAM Education's impact.

Table 4. Teachers' opinion on STEAM Education impact.

Impact of STEAM Education	Percentiles		
	25th	50th (Median)	75th
Students develop interdisciplinary knowledge (STEAM literacy)	4	5	5
Students develop creative thinking	4	5	5
Students develop interpersonal skills and cooperative work	4	5	5
Students focus more on their learning	4	4,5	5
Students feel more autonomous in their learning	4	4	5
Students develop critical thinking	4	4	5
Gives significance to learning while connected to the student's context/reality	4	4	5
Students more easily remember what they learned	4	4	5
Reduces the gap between boys and girls in STEM	3	4	5
Students effort more into what they are learning	3,75	4	5
Ethical/human values development	4	4	4,25
Students have an environment of error as a learning opportunity	4	4	4
Students understand more easily what they are learning	3	4	4,25
Encourages environmental education	3	4	4,25
Classroom climate is improved (fewer indiscipline problems)	3	4	4

Furthermore, teachers answered four questions directly intended to explore their predisposition toward STEAM: 1) I intend to further develop my skills in STEAM; 2) I am willing to use STEAM Education; 3) I am interested in advanced programs involving STEAM, and 4) I would recommend STEAM Education to my fellow teachers. Responses to those questions had medians of 4 (Agree) and 5 (Strongly agree). This result indicates teachers' predisposition toward STEAM.

Now we remind the reader of our second research question – How did the teacher training program affect teachers' abilities on planning STEAM activities?

Still regarding survey I, we explored teachers' self-efficacy in applying the knowledge areas of Science, Technology, Engineering, Arts/humanities, and Mathematics in STEAM plans. Results show they mostly indicated self-efficacy in considering Arts and Humanities, Mathematics, and Science (percentile 50^{th} = 4, agree), but they disagreed about Engineering and Technology (percentile 50^{th} = 2, disagree). A Friedman test confirmed those differences between areas were significant (Friedman $\chi^2_{(4)} = 13.77$, $p = .008$). The sixth question of this block addressed teachers' self-efficacy in planning STEAM activities (in general), this data will be used afterwards in a pre-post-test design.

Now on, we present the result analysis of data collected at the end of the program. The 14 STEAM plans teachers developed were analysed to verify which STEAM areas and which active learning teaching methods were applied. Results showed all plans contained at least the areas of Science and Art/Humanities. Moreover, half of them involved the five STEAM areas. This finding indicates teachers embraced the interdisciplinarity enterprise.

A McNemar test verified whether there is a change between teachers' initial self-efficacy in considering each area of STEAM (from the survey I) and their actual use in the plans. Engineering was the sole area with a statistically significant change ($\chi^2_{(1)} = 4.9$, $p = .03$). Nine teachers who had indicated low efficacy in considering Engineering then applied it to the STEAM plan.

Despite having a non-significative change, it is noteworthy to observe three teachers indicated efficacy in considering Technology initially, but they didn't use it in their plan. Similarly, five teachers who had indicated efficacy in considering Mathematics didn't use it as well. We should remember most participants are from the area of Humanities. Non-use of some knowledge areas in the plans does not mean necessarily a negative signal. It can be interpreted as the learning that in STEAM the knowledge areas must be used substantially, instead of in a superficial approach.

Regarding the application of active learning teaching methodologies, teachers applied Inquiry-Based Learning (6), Project-Based Learning (5), and Game-Based Learning (1) in their STEAM plans. This information was crossed with each participant's response on prior use of that specific teaching methodology (data extracted from part A of the survey I within the dimension Usage. The result indicated that 71% of the teachers applied teaching methodologies in the STEAM plans they were not habituated to using.

From this point, we present an analysis of part A of survey II. This part had a repeated measure of teachers' self-efficacy in planning STEAM activities. Initially, teachers indicated a median of 3, meaning "Neutral" (survey I); and after the program, it changed to 4, meaning "Agree" on self-efficacy in planning STEAM activities. A Wilcoxon Signed Ranks Test showed this difference was statistically significant ($Z = -3.071$, $p = .002$).

From a more qualitative perspective, five open-ended questions explored the process of planning STEAM activities (part B of survey II). In Table 5, each question is presented as a topic followed by the categories induced from data and its representative responses.

Table 5. Teachers' opinions after enrolling in a program on planning STEAM activities.

Topic		Category	Representative response
Difficulty in doing STEAM activity plans		Merging different knowledge areas (10)	"Significant inclusion and integration of STEAM areas into plans" (P10).
		Setting a teaching method (3)	"Defining the appropriate methodological approach to the activity" (P12).
		School management resistance (2)	"considering the receptivity of the school management" (P01).
Pros and cons of STEAM Education	Pros	Interdisciplinarity (9)	"Teachers can connect a content to other knowledge areas" (P02).
		Authentic context and connexion to students' reality (5)	"STEAM fosters new or creative connections with the real world and contextualized problems" (P10).
		Variety of teaching methods (4)	"We can integrate STEAM areas while using teaching methods other than direct instruction" (P07).
	Cons	Time-consuming (3)	"STEAM requires a greater effort to plan the activities" (P02).
		Lack of expertise in some areas (2)	"Teachers are required to have competence in more knowledge areas" (5).
		Risk of content superficiality (1)	"The content might stay shallow" (P09).
Positive aspects of doing a STEAM activity plan		Incentive learning about other areas (5)	"It encourages professors to learn about areas beyond their disciplines" (P02).
		Planning ability (5)	"Teachers can exercise a critical eye on their plans. They need clear, complete and coherent objectives to do STEAM" (P10).
		Learning collaboratively (2)	"Knowledge and experience exchanges allow exploring the potential of colleagues" (P03).
		Learning about STEAM Education (1)	"Learning more about STEAM" (P07).
Suggestion to STEAM		Teacher training (6)	"The concepts of STEAM should be taught and disclosed" (P06).
		Revise the presence of Humanities (2)	"Most STEAM cases cover exclusively the areas of technology and engineering, while Humanities play a secondary and illustrative role" (P01).
		Approximating professionals from Engineering and Technology (1)	"Strengthen the relationship between professionals from engineering and technology professionals and education" (P03).
Teachers' required abilities for pursuing STEAM Education		Openness to changes and continuous learning (9)	"Teachers need to be open to learning new ways of working" (P07).
		Collaborative ability (3)	"Teamwork and collaboration, availability to learn new methodologies" (P13).
		Using technological tools in education (3)	"Teachers need to know about technological tools in education" (P05).

The first question was – What is the most difficult part of making STEAM activity plans? Results showed merging different knowledge areas seems to be the harder part, stated by 10 teachers. They also cited setting a teaching method and school management resistance.

On the other hand, interdisciplinarity was the most frequent category about the pros of STEAM Education, with nice citations. Teachers also mentioned authentic context and connexion to students' reality and a variety of teaching methods as advantages of STEAM. Few teachers stated about cons of STEAM Education: time-consuming, teachers' lack of expertise in some knowledge areas, and risk of working content superficially.

The third question directly relates to their learning experience in planning STEAM activities. They were asked, – What was a positive aspect of directly developing STEAM materials as a pre-service teacher? Most teachers highlighted incentives for learning about other knowledge areas and developing planning ability. Also learning collaboratively, and learning about STEAM Education.

The fourth question analysed was – What is your suggestion for STEAM education after you developed STEAM materials for yourself? Their answers indicated the necessity of teacher training on STEAM, followed by revising the presence of Humanities. One teacher suggested approximating professionals from Engineering and Technology to the school.

Finally, yet importantly, the question - What kind of abilities do you think teachers need for STEAM Education after you developed STEAM materials for yourself? Nine teachers pointed to openness to changes and continuous learning. Teachers mentioned collaborative ability (3), and the efficacy of using technological tools in education (3).

DISCUSSION

What are teachers' initial opinions related to STEAM Education?

Results showed a significant global difference between teachers' evaluation of educational approaches considering the dimensions of Knowledge, Usage, Willing to use and Appropriateness to STEAM. Specific tests demonstrated a congruency between what teachers indicate they are willing to use and what they consider appropriate to STEAM Education. In fact, most educational approaches had no significant difference between those two dimensions.

The difference lies principally when comparing Knowledge to Usage, and when comparing each one of them with Appropriateness to STEAM. We cannot affirm whether the level of teachers' knowledge of those educational approaches was sufficient for their application. Park et al. (2016) point to a mismatch between teachers' perception and actual practices in STEAM Education. In this sense, general feeling of insufficient experience and knowledge of STEAM Education may negatively affect its inclusion in curriculums at all school levels.

In the opposite sense to most educational approaches, direct instruction was, on one hand, the most known and commonly used educational approach, but on the other hand, teachers are not so willing to use it, and it was the least evaluated approach in terms of appropriateness to STEAM. Interestingly, that shows an open avenue to explore other teaching methods.

Teachers agreed regarding a list of 15 positive impacts of STEAM. This result suggests a positive view of STEAM education. Additionally, as stated before, there was congruency between what they are willing to use and what they consider appropriate to STEAM. Corroborating to all that, they agreed with four questions directly related to predispositions toward STEAM. Rodrigues-Silva and Alsina (2021) argue teachers' beliefs, prior knowledge and experiences should be considered in their professional development. Accordingly, in the first stage of the course, teachers were able to share ideas and concerns about STEAM.

How did the program affect teachers' abilities on planning STEAM activities?

Teachers' self-efficacy about considering STEAM areas in STEAM plans was heterogeneous. They agreed on efficacy in considering Art/humanities, Mathematics and Science, but disagreed about Engineering and Technology. Other studies show teachers have difficulty differentiating Engineering and Technology (Kim & Bolger, 2017). Thus, a teacher's suggestion on approximating professionals from Engineering and Technology to the school seems rather pertinent.

Teachers' efficacy in considering Engineering in STEAM plans had a significant increase. Nine teachers who had indicated low efficacy then considered this knowledge are in their STEAM plans. Researchers agree planning STEAM is challenging for teachers (Boice et al., 2021; Cook et al., 2020). Accordingly, merging different knowledge areas was the most frequent category on the open-ended question about difficulties in doing STEAM plans. This is a frequently reported issue in the literature (Carmona-Mesa et al., 2019; Cook et al., 2020)

In spite of the difficulty, teachers indicated interdisciplinarity as an advantage of STEAM Education and doing STEAM plans incentives them to learn about other knowledge areas. There was evidence they overcame this difficulty, half of the STEAM plans embraced the five STEAM areas. Art/Humanities and Science were present in all of them.

Similarly, they reported setting a teaching method as being a difficult aspect when doing STEAM activities plans in the open-end questions. Interestingly, they also pointed variety of teaching methods as an advantage of STEAM Education. Analysis of the STEAM plans confirmed they applied active learning teaching methods, especially inquiry and project-based learning. It is noteworthy to say more than 70% of them used teaching methods that were new to them. A teacher wrote –"We can integrate STEAM areas while using teaching methods other than direct instruction" (P07). Those findings show teachers may consider interdisciplinarity and active learning teaching methods challenging. But they support them as advantages of STEAM, and they were able to surpass those difficulties through the STEAM plans.

Teachers' achievements are intimately connected to the teacher training program features. In the beginning, there were sessions on theoretical scaffolding on STEAM and active learning teaching methods. Afterwards, this theory helped teachers to develop STEAM plans. In addition, the two rounds of feedback (with mentoring) and the peer and self-assessment were redirected teachers' so they could accomplish the STEAM plans. For example, they were demanded to apply the STEAM areas in an interdisciplinary manner, wherein one area was neither addressed superficially nor with a subservient role. They were also suggested to investigate and explicit the teaching method used.

Of course, all that process is laborious, especially when teachers are still developing the abilities to plan STEAM activities. Accordingly, they warned time-consuming might be a disadvantage of STEAM Education. That concern is reported by authors from other countries, such as in Korea (Park et al., 2016).

CONCLUSION

Teachers' self-efficacy in planning STEAM activities augmented significantly with the training program, from percentile 3, meaning neutral, to 4, agreement. They confirmed in an open-ended question the development of planning ability is a positive aspect of doing STEAM activity plans. Participants indicated openness to changes and continuous learning as a required ability for teachers for pursuing STEAM Education. Accordingly, their most frequent suggestion for STEAM education was teacher training. At this point, we recall the gap between teachers' knowledge of educational approaches and their appropriateness to STEAM.

Results allowed us to conclude this online teacher-training program on planning STEAM activities allowed teachers to explore active learning teaching methods, augmented their self-efficacy in considering the STEAM areas in the plans, and in conclusion, was able to conduct teachers to accomplish the task of planning STEAM activities.

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ARTICLE 8

Putting engineering on the table

A STEAM activity of reverse engineering and mathematics

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Poniendo la ingeniería sobre la mesa: una actividad STEAM de ingeniería inversa y matemáticas

Putting engineering on the table: a STEAM activity of reverse engineering and mathematics

Colocando a engenharia sobre a mesa: *uma atividade STEAM de engenharia reversa e matemática*

Jefferson Rodrigues-Silva
Instituto Federal de Minas Gerais, Departamento de Ingeniería Mecánica, Arcos, Minas Gerais, Brasil. Doctorando en Educación en la Universidad de Girona, España.
jeffe.rodri@gmail.com.br | https://orcid.org/0000-0002-8334-2107

Marcela Silva-Hormazábal
Universidad Austral de Chile, Puerto Montt, Los Lagos, Chile. Doctoranda en Educación en la Universidad de Girona, España.
marcela.silva@uach.cl | https://orcid.org/0000-0002-1955-1633

Ángel Alsina
Universidad de Girona, Departamento de Didácticas Específicas, Girona, Cataluña, España. Catedrático de Didáctica de las Matemáticas en la Universidad de Girona, España.
angel.alsina@udg.edu | https://orcid.org/0000-0001-8506-1838

Resumen
Se explora la ingeniería inversa como una estrategia didáctica para la interdisciplinariedad entre la ingeniería y las matemáticas en educación primaria. En la primera parte, se fundamenta teóricamente la educación STEAM y el Aprendizaje Basado en el Diseño (ABD) en el sentido de la ingeniería inversa. En la segunda parte, se presenta el diseño de una actividad STEAM en la que los estudiantes hacen ingeniería inversa de una mesa y seleccionan materiales de un catálogo a partir de condiciones restrictivas de medida, precio y sostenibilidad. Además, se exponen los resultados de su implementación a 23 estudiantes de una escuela de Girona, España. Se ha evidenciado que la actividad es pedagógicamente potente en cuanto al aprendizaje de las matemáticas y de la ingeniería. Su simplicidad y factibilidad de reproducción (se proporciona una guía en formato editable) ayuda al profesorado a entender que la ingeniería no está limitada a planteamientos complejos y costosos.
Palabras clave: *Ingeniería inversa. Resolución de problemas. Sostenibilidad. Educación STEAM. Educación Primaria.*

Abstract
Reverse engineering is explored as a didactic strategy for interdisciplinary between engineering and mathematics in primary education. In the first part, we theoretically scaffold STEAM education and Design-Based Learning (DBL) in the sense of reverse engineering. In the second part, we present a STEAM activity plan in which students do reverse engineering of a table and then select materials from a catalogue with restrictive demands of dimensions, price and sustainability. The description of this activity is accompanied by the results of its implementation with 23 students from a Spanish school in Girona. The activity is shown to be pedagogically powerful in learning mathematics and engineering. Its simplicity and reproducibility (we provide a worksheet in an editable format) help teachers to understand that engineering is not limited to complex and costly approaches.
Keywords: *Reverse engineering. Problem solving. Sustainability. STEAM education. Primary education.*

Resumo
Explora-se a engenharia reversa como estratégia didática para a interdisciplinaridade entre engenharia e matemática no ensino fundamental. Numa primeira parte, fundamenta-se teoricamente a educação STEAM e a Aprendizagem

Baseada em Design (ABD) no sentido de engenharia reversa. Numa segunda parte, apresenta-se o planejamento didático de uma atividade STEAM em que os alunos fazem engenharia reversa de uma mesa e selecionam materiais de um catálogo com demandas restritivas de medidas, preço e sustentabilidade. A descrição dessa atividade é acompanhada dos resultados da sua execução a 23 alunos de uma escola de Girona na Espanha. Demonstrou-se que essa atividade é pedagogicamente potente em termos de aprendizagem de matemática e engenharia. Sua simplicidade e reprodutibilidade (fornece-se a guia de aprendizagem em formato editável) ajudam os professores a entenderem que a engenharia não se restringe a abordagens complexas e caras.
Palavras-chave: *Engenharia reversa. Solução de problemas. Sustentabilidade. Educação STEAM. Ensino Fundamental.*

1 Introducción

A medida que el mundo se desarrolla tecnológicamente, la sociedad se integra a la ingeniería y sus tecnologías. Este fenómeno genera una necesidad de comprensión del individuo sobre la ingeniería en conexión con otras áreas de conocimiento (MOORE *et al.*, 2014) para que pueda entender, vivir y actuar (transformar) sobre este mundo. Desde esta perspectiva, cobran relevancia pedagogías de enfoque interdisciplinar como la educación STEM (interdisciplinariedad entre Ciencias, Tecnología, Ingeniería y Matemáticas) y la educación STEAM, que considera también las Artes y Humanidades dentro del acrónimo (PERIGNAT; KATZ-BUONINCONTRO, 2019).

Estos abordajes interdisciplinares van conquistando espacio en la investigación educativa y en los currículos de países como Estados Unidos (NGSS, 2013) y Corea (JEONG; KIM; TIPPINS, 2019). Siguiendo esta línea, España ha explicitado recientemente competencias interdisciplinares STEM en su currículo de educación primaria (MEFP, 2022). Las propuestas curriculares que establecen competencias STEM/STEAM han introducido una disciplina tradicionalmente no considerada en los currículos de las primeras edades, la ingeniería, promoviendo así el acercamiento a la ingeniería temprana en el contexto escolar (MOORE *et al.*, 2014; RODRIGUES-SILVA; ALSINA,2023).

En consecuencia, esta innovación curricular requiere un planteamiento metodológico acorde al desarrollo del pensamiento de diseño de ingeniería. En este contexto, se ha difundido el Aprendizaje Basado en el Diseño (ABD) como una metodología apropiada para la enseñanza-aprendizaje del diseño de ingeniería (LADACHART *et al.*, 2022). No obstante, esta metodología tiene dos abordajes o líneas diferentes dependiendo del objetivo que persiga:

a) Ingeniería directa: se explora un problema con el objetivo de desarrollar una solución de ingeniería, como es el diseño y construcción de un producto (YOUNIS; TUTUNJI, 2012).

b) Ingeniería inversa: se analiza de forma retrospectiva un producto existente para entender su proceso de diseño, función y el problema al que responde (LADACHART *et al.*, 2021, 2022; YOUNIS; TUTUNJI, 2012; ZHONG; KANG; ZHAN, 2021),

Si bien la *ingeniería directa* parece ser el sentido más natural de la ingeniería, algunos investigadores han apostado por el ABD en el sentido de la *ingeniería inversa* como primer acercamiento al pensamiento de diseño (LADACHART *et al.*, 2022; YOUNIS; TUTUNJI, 2012). Esto debido a que el sentido de *ingeniería inversa* (del concreto al abstracto) posibilita construir la base de la competencia de diseño con la cual, posteriormente, desarrollar actividades de *ingeniería directa* (LADACHART *et al.*, 2022).

No obstante, la ingeniería en el contexto escolar ha sido poco investigada e implementada debido a que, tal como se ha mencionado anteriormente, su incorporación en el currículo ha sido reciente y focalizada en algunos países. Por ende, lo mismo sucede con la ingeniería inversa, la cual a pesar de las evidencias de su potencialidad (LADACHART *et al.*, 2022), aún no ha sido suficientemente explorada a nivel escolar. Consecuentemente, se puede afirmar que faltan experiencias de ingeniería temprana general y de ingeniería inversa en particular en conexión con las matemáticas. Tampoco hay muchos estudios que expliquen cómo adecuarla a los niveles educativos iniciales (ATA-AKTÜRK; DEMIRCAN, 2021). Además, generalmente los profesores desconocen y tienen preconcepciones sobre ingeniería que les desmotiva a considerarla en sus clases (HAMMACK; VO, 2019).

Considerando estos antecedentes, el objetivo de este artículo es explorar la ingeniería inversa como una estrategia didáctica para la interdisciplinariedad entre la ingeniería y las matemáticas en educación primaria. Para ello, se presenta el planteamiento e implementación de una actividad STEAM de ingeniería inversa de una mesa y posterior selección de materiales de un catálogo con condiciones restrictivas de medida, precio y sostenibilidad.

2 Marco teórico

En este apartado, se presentan brevemente los marcos teóricos sobre la educación STEAM y las conexiones entre ingeniería y matemática a través de la resolución de problemas e ingeniería inversa.

2.1 La educación STEAM

El enfoque STEAM es un abordaje educativo que se fundamenta en la premisa de una educación basada en la interdisciplinariedad de las Ciencias, Tecnología, Ingeniería, Artes y Matemáticas (PERIGNAT; KATZ-BUONINCONTRO, 2019). En su desarrollo, se ha observado como este abordaje tiene la intención de incorporar áreas del conocimiento que tienen un papel central en la sociedad actual – ingeniería y tecnología – pero que generalmente no eran consideradas en los currículos de educación primaria (MOORE *et al.*, 2014).

Acorde a la contemporaneidad, STEAM ha sido empapada de una serie de direccionamientos, generalmente desde un prisma socioconstrutivista, como lo son el aprendizaje activo, colaborativo, auténtico, significativo y lúdico (SCHLESINGER *et al.*, 2020; ZOSH *et al.*, 2018). Así también, se ha situado bajo metodologías de enseñanza activas como el Aprendizaje Basado en Proyectos (ABP) y el Aprendizaje Basado en Diseño (ABD) (LADACHART *et al.*, 2022), para la implementación de STEAM.

Diversas investigaciones defienden la aproximación interdisciplinar como una necesidad para abordar la comprensión y solución de problemas de manera creativa, que permitan avanzar hacia una transformación de la sociedad (FLORENTINO; RODRIGUES, 2015; POLITI, 2019). Al respecto, una revisión bibliográfica realizada por Marín-Marín *et al*. (2021) indican que STEAM sigue en proceso de consolidación como línea de investigación. Sin embargo, este mismo estudio evidenció la estabilidad del constructo creatividad en las investigaciones de STEAM desde su creación en 2007.

2.2 Conexión entre ingeniería y matemáticas en la competencia de diseño de ingeniería

Se aboga que, en la educación STEAM, todas las áreas del acrónimo deben ser consideradas como un todo, pero que en el ámbito de una actividad singular STEAM la interdisciplinaridad puede ocurrir a partir de al menos dos disciplinas (PERIGNAT; KATZ-BUONINCONTRO, 2019; RODRIGUES-SILVA; ALSINA, 2023). Esta configuración permite establecer vínculos más genuinos entre las disciplinas. En este marco, un primer argumento a favor de la interdisciplinariedad entre ingeniería y matemática es que esta conexión surge de manera auténtica desde la infancia (PARK; PARK; BATES, 2018). En esta línea, se ha documentado que los niños presentan una curiosidad y creatividad innata que les permiten explorar el mundo de manera holística: para investigar su naturaleza (esencia científica); para razonarlo (esencia matemática) y para transformarlo de alguna forma (esencia ingenieril) (ATA-AKTÜRK; DEMIRCAN, 2021). De acuerdo con esta idea, Bagiati y Evangelou (2016) observaron que, durante el juego libre de construcción con bloques, niños de tres a cinco años muestran comportamientos precursores del pensamiento de ingeniería: identifican necesidades y problemas, establecen metas, prueban soluciones y colaboran entre sí. Además, muestran comportamientos precursores del álgebra temprana a través del reconocimiento de patrones repetitivos y la construcción de estos con un núcleo de repetición sencillo (INCHAUSTEGUI; ALSINA, 2020).

En este escenario, es posible observar cómo estos contextos integradores posibilitan el desarrollo de habilidades como la resolución de problemas. Al respecto, el Consejo Nacional de Profesores de Matemáticas (*National Council of Teachers of Mathematics*, NCTM) sitúa esta habilidad como un eje transversal en el aprendizaje de las matemáticas, a partir del que los estudiantes deberían "construir nuevos conocimientos a través de la resolución de problemas; resolver problemas que surjan de las matemáticas y de otros contextos" (NCTM; 2000, p. 55). En particular, la resolución de problemas de ingeniería fomenta el pensamiento creativo ya que, durante el diseño de ingeniería, el alumnado debe ejercitar su creatividad al considerar una larga lista de restricciones para solucionar un problema (WULF, 2001). Asimismo, este tipo de actividad se vincula con la Educación para el Desarrollo Sostenible (EDS) (UNESCO, 2017), por ejemplo, al observar, reflexionar y tomar decisiones sobre los desperdicios asociados a la producción ingenieril.

2.3 Ingeniería inversa

El Aprendizaje Basado en el Diseño (ABD) es defendido como una metodología de enseñanza activa que permite el desarrollo de la competencia de resolución de problemas, en específico el diseño de ingeniería. Esta competencia reúne características importantes, tales como pensamiento crítico y creatividad para proponer, experimentar, evaluar soluciones bajo restricciones y controlar riesgos considerando la relación compleja de problema-solución. Adicionalmente, promueve actitudes como la empatía para entender los problemas de los demás y la tolerancia frente a la ambigüedad (LADACHART *et al.*, 2022; YOUNIS; TUTUNJI, 2012).

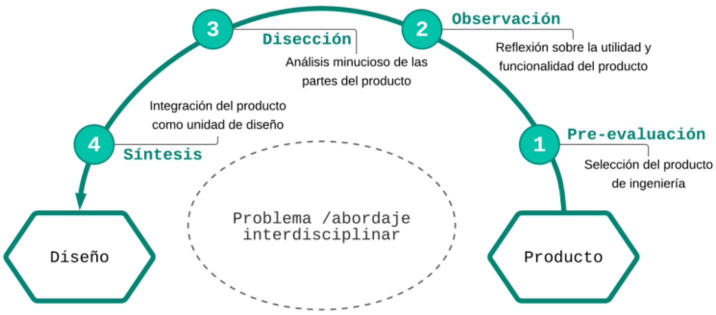
La implementación de metodologías de ABD usualmente se da en el sentido de ingeniería directa, es decir, el alumnado parte de un problema para luego desarrollar el diseño de un producto o sistema (solución de ingeniería) (LADACHART *et al.*, 2022). Sin embargo, el alumnado suele tener dificultades para llevar a cabo este tipo de actividad, debido a que las tareas de diseño propuestas requieren aplicar la competencia de diseño, que no ha sido desarrollada previamente (ZHONG; KANG; ZHAN, 2021). Las dificultades detectadas han puesto de manifiesto la necesidad de que el alumnado comprenda previamente el diseño de productos ya existentes, particularmente respecto a la ingeniería temprana, para luego estar en condiciones de hacer sus propios diseños. Este proceso se denomina ingeniería inversa, que permite observar y analizar un producto en concreto para, de manera retroactiva, llegar a un diseño que responde a un problema de ingeniería (LADACHART *et al.*, 2022; ZHONG; KANG; ZHAN, 2021).

De esta forma, como punto de partida de la ingeniería inversa, se establece la manipulación de objetos concretos avanzando hacia la abstracción en forma de diseño de ingeniería (SCHELLINGER; JABER; SOUTHERLAND, 2022). Este panorama permite establecer conexiones entre la ingeniería inversa y la modelación matemática, pues parte de una situación del mundo real, el objeto de ingeniería, y luego se convierte en un modelo matemático, el diseño de ingeniería. Al respecto, Alsina y Salgado (2021) argumentan que la modelización matemática puede ser introducida en el aula desde la educación infantil. A su vez, Ladachart *et al.* (2021) exponen ventajas de la ingeniería inversa relacionadas con su capacidad de transformar la visión del alumnado respecto al origen de los productos: se parte de la idea previa de generación espontánea de los objetos, hacia una consciencia de los procesos intelectuales que conllevan los productos de diseños de ingeniería (LADACHART *et al.*, 2021).

Respecto a los modelos de ingeniería inversa, algunos autores consideran diversas etapas que van desde una pre-evaluación del producto existente hasta su diseño, rediseño y construcción de un nuevo producto (YOUNIS; TUTUNJI, 2012). Sin embargo, la ingeniería inversa sumada a la actividad de rediseñar ya podría ser interpretada como una extensión de ingeniería directa. Además, otras investigaciones han apuntado que el diseño de un nuevo producto puede no ser factible o pertinente cuando se trabaja con niños más pequeños (LADACHART *et al.*, 2021, 2022).

Por lo tanto, en esta investigación se propone un modelo de ingeniería inversa para ABD adecuado a la ingeniería temprana. Este modelo propone cuatro fases de la ingeniería inversa: a) *pre-evaluación*, *se s*elecciona el producto de ingeniería (objeto concreto); b) *observación*, se visualiza el producto en su unidad, reflexionando sobre su utilidad y funcionalidad; c) *disección*, se analiza minuciosamente las partes del producto: función, dimensión, material, etc.; y d) síntesis, donde se concibe el producto como una unidad integrada, pero de forma abstracta como un diseño del producto (Figura 1).

Figura 1: Modelo de ingeniería inversa



Fuente: elaboración propia.

En el desarrollo de las fases se potencia la conciencia sobre la existencia, función y cómo cada componente trabaja en conjunto para garantizar que el producto cumpla su funcionalidad respecto al problema. Además, es importante que todas las fases de ingeniería inversa se desarrollen en torno a un problema y un abordaje interdisciplinar. Por último, es necesario aclarar que estas fases tienden a ocurrir en el orden presentado, pero son dinámicas e iterativas.

3 Propuesta de actividad STEAM: Ingeniería inversa de una mesa

En esta sección se presenta la fundamentación, el planteamiento y la descripción de la una actividad STEAM, explicitando las etapas necesarias para llevarla a cabo. Además, se complementa esta descripción con resultados de implementación en un grupo de 23 estudiantes de quinto curso de primaria (10-11 años), de una escuela de primaria de Girona (España). Finalmente, se hace una evaluación de la actividad con base en criterios de calidad para la enseñanza de ingeniería en esta etapa.

En relación con las características del grupo participante, según los datos aportados por la escuela, estos estudiantes poseen un nivel medio de comprensión lectora y un nivel medio de comprensión matemática. Para esta investigación, se han considerado datos de sólo 18 estudiantes, quienes aceptaron de forma voluntaria participar en esta investigación y sus padres o tutores firmaron el consentimiento de registro de audio e imágenes y el uso de sus producciones.

3.1 Fundamentación de la actividad

La actividad *Ingeniería inversa de una mesa* comparte elementos de la propuesta Zapato y Metro de Reggio Emilia, donde estudiantes de educación infantil aplican conocimientos sobre unidades de medida no convencionales para diseñar una mesa bajo la consigna: *construcción de una mesa idéntica a la mostrada en la clase* (NOVO, 2019). Con respecto a la gestión del aula, se propone la utilización del modelo de interacción maestro-estudiantes ofrecido por el programa

Activando la Resolución de Problemas en las Aulas (ARPA) que incluye cuatro momentos: entrega, activación, consolidación y discusión (PERDOMO-DÍAZ; FELMER, 2017). Estos momentos son mencionados a lo largo de la descripción de la actividad.

3.2 Planteamiento de la actividad

A continuación, en la Tabla 1 se presenta el planeamiento de la actividad. Para ello, se han considerado las preguntas de diseño didáctico para actividades STEM de Aguilera *et al.* (2022), así como también, el currículo español (MEFP, 2022) y el modelo de enseñanza de ingeniería en la educación primaria propuesto por Moore *et al.* (2014).

Tabla 1: Preguntas y diseño didáctico para sesión STEAM.

Pregunta	Diseño didáctico
¿Para qué?	**Objetivo:** Resolver problemas no rutinarios por medio de la ingeniería inversa de un objeto concreto
¿Qué?	**Contenidos de matemáticas (grandes ideas-ejes):** Medición: unidades de medida de longitud, conversión. Números: naturales y decimales – sistema monetario. Operaciones: adición, división, multiplicación. **Contenidos de ingeniería:** Dibujo técnico: cotas. Mecanismos de unión: tornillos y soldadura. Selección de materia prima. Cálculo de presupuesto de un proyecto de ingeniería.
	Competencias Específicas Matemáticas (CEM) (MEFP, 2022): Interpretar situaciones de la vida cotidiana, proporcionando una representación matemática de las mismas (CEM1). Resolver situaciones problematizadas, aplicando diferentes técnicas, estrategias y formas de razonamiento (CEM2). Reconocer y utilizar conexiones entre las diferentes ideas matemáticas, así como identificar las matemáticas implicadas en otras áreas o en la vida cotidiana (CEM5). Comunicar y representar, procedimientos y resultados matemáticos (CEM6). Desarrollar destrezas sociales, participando activamente en equipos de trabajo heterogéneos con roles asignados (CEM8). **Competencias específicas de ingeniería** (MOORE *et al.*, 2014)**:** Diseño de ingeniería. Entender un objeto como un producto de ingeniería, observando sus diferentes partes y elementos de unión. Representar gráficamente las partes de un objeto con cotas. Tomar de decisiones de ingeniería ponderando sobre situaciones restrictivas y o contradictorias. **Competencias interdisciplinares** (MEFP, 2022)**:** Competencia STEM3. Realiza, de forma guiada, proyectos, diseñando, fabricando y evaluando diferentes prototipos o modelos, adaptándose ante la incertidumbre, para generar en equipo un producto creativo con un objetivo concreto, procurando la participación de todo el grupo y resolviendo pacíficamente los conflictos que puedan surgir. Competencia ciudadana CC4. Comprende las relaciones sistémicas entre las acciones humanas y el entorno, y se inicia en la adopción de estilos de vida sostenibles, para contribuir a la conservación de la biodiversidad desde una perspectiva tanto local como global.

	Producto: Propuesta de una mesa según condiciones requeridas en un reto de ingeniería.
	Prácticas STEAM: Conexiones de ingeniería y matemáticas.
¿Cómo?	**Contexto:** Problema ficticio (reto) pero asociado a elementos cotidianos (una mesa).
	Evaluación: Colaborar en el reparto de tareas, asumiendo y respetando las responsabilidades individuales asignadas y empleando estrategias de trabajo en equipo sencillas dirigidas a la consecución de objetivos compartidos. Comunicar en diferentes formatos las conjeturas y procesos matemáticos, utilizando lenguaje matemático adecuado. Desarrollar estrategias de solución de un reto de ingeniería, seleccionando entre varias posibilidades de respuesta.
	Cooperación: Los estudiantes trabajan en equipos y a partir de juego de roles. **Co-enseñanza de equipo:** Profesor de matemáticas y de ingeniería (FRIEND; COOK, 2017).

Fuente: elaboración propia.

3.3 Descripción y análisis de la actividad

A continuación, en la Tabla 2 se presenta el panorama general de la sesión.

Tabla 2: Panorama general de la sesión

Actividad: Ingeniería inversa de una mesa	**Nivel: Quinto curso de educación primaria (10 a 11 años)**	
Metodología: Aprendizaje Basado en el Diseño – sentido de Ingeniería inversa	**Enfoque:** Educación STEAM centrada en las áreas de matemáticas e ingeniería	**Finalidad:** Resolver problemas no rutinarios (reto de ingeniería).
Tiempo de ejecución: 90 minutos	**Materiales:** Objeto de observación (mesa), cinta métrica, identificadores de roles, fichas de trabajo (material complementar).	**Producto final:** Diseño a partir de la ingeniería inversa de un objeto del entorno.

Fuente: elaboración propia.

3.3.1 *Actividad previa*

En una sesión anterior, se invita a los estudiantes a descubrir la ingeniería presente en su hogar y a hablar sobre ella con sus familiares.

3.3.2 *Fase de inicio: discusión sobre la ingeniería (10 minutos)*

Se empieza la actividad con una discusión en torno a la pregunta ¿qué productos de ingeniería han observado en su hogar? Luego, se les plantea la pregunta ¿qué elementos u objetos de esta clase creen que tienen ingeniería? Posteriormente, mostrando una mesa, se les pregunta qué hay de ingeniería en ella y se exploran las diversas ideas.

Durante la implementación de esta actividad, se ha observado que los estudiantes son conscientes de la existencia de objetos que son producto de ingeniería en sus hogares como mesas, sillas y ordenadores. Un estudiante, por ejemplo, menciona "es que toda mi casa es ingeniería… es que todo el edificio tiene ingeniería" (Est.01).

Siguiendo las reflexiones anteriores, se les pregunta ¿qué es la ingeniería? Considerando sus respuestas, se sugiere que la ingeniería se dedica a la transformación de recursos de la naturaleza para el bienestar humano. Seguidamente, se enfatiza que las personas ingenieras necesitan conocimientos y habilidades de diversas áreas del conocimiento, como las matemáticas y las ciencias, para el diseño productos de ingeniería que solucionen problemas de la sociedad. Para ello, se necesita la creatividad ya que estos problemas suelen involucrar múltiples restricciones como peso, tamaño y precio (WULF, 2001).

Esta aclaración previa es importante porque diversas investigaciones apuntan que los niños pueden presentar ideas equivocadas o estereotipadas en torno a la ingeniería (CHOU; CHEN, 2017; SILVA-HORMAZÁBAL; RODRIGUES-SILVA; ALSINA, 2022).

3.3.3 Fase de desarrollo: desafío de ingeniería (60 minutos):

En esta fase, se les motiva a convertirse en ingenieros e ingenieras y se presenta el reto:

Figura 2: Reto propuesto en la actividad

> *"La escuela quiere comprar 10 nuevas mesas para los estudiantes, para ello ha pedido a empresas de ingeniería que le entreguen un presupuesto. Estas mesas deben cumplir 3 criterios para ser aprobadas:*
>
> - *Medidas iguales a las mesas actuales*
> - *precio conveniente*
> - *sostenibilidad (evitar desperdicio de materia prima)"*

Los estudiantes son organizados en equipos de cuatro a seis integrantes que representan empresas de ingeniería. Cada uno elige libremente un rol (metrología, diseño, finanzas-cálculo, organización, portavoz y registro de procedimientos) y se identifica con una credencial, tal como se ve en la figura 3. El maestro enfatiza que todos los integrantes deben aportar ideas y apoyar las diferentes funciones.

Figura 3: Niña con credencial rol de metrología

Fuente: elaboración propia.

Se inicia la ingeniería inversa con la fase de *pre-evaluación*. En un primer momento, el maestro selecciona el objeto de estudio y en actividades posteriores existe la posibilidad de que el alumnado mismo pre-evalúe un objeto de su interés. En específico, en esta actividad se estudia la mesa por ser un objeto simple y del contexto cercano de los estudiantes. En cuanto a la gestión del aula, se realiza la *activación*, donde "la interacción del docente con los grupos es solo a través de preguntas" (PERDOMO-DÍAZ; FELMER, 2017, p. 434).

Luego, durante la segunda fase de *observación*, se explora el objeto. Como se presenta en la Figura 4, los estudiantes examinan la mesa como un todo y discuten su funcionalidad.

Figura 4: Estudiantes examinan el objeto de estudio (fase de observación)

Fuente: elaboración propia.

En la tercera fase de ingeniería inversa, la *disección,* los estudiantes analizan las partes que constituyen la mesa, incluyendo los materiales con los que se ha elaborado y cómo estas partes están unidas. Tal como se observa en la Figura 5, los estudiantes toman medidas para luego discutirlas. Se destaca que, en la parte izquierda, una niña mide la pata en dirección vertical, mientras que en la derecha de la figura un alumno mide la curvatura del componente.

Figura 5: Medición de los componentes de la mesa. Izquierda: una niña midiendo el largo de una pata de la mesa. Derecha: un niño midiendo el soporte entre las patas.

Fuente: elaboración propia.

Algunos diálogos del alumnado evidencian la disección de la mesa y la consciencia de sus componentes. Por ejemplo, una estudiante menciona "las patas, los tubos laterales y la tabla de madera… el perímetro de la mesa" (Est.02). Respecto a la ingeniería, un alumno hace alusión a elementos de unión cuando dice "los clavos aguantan las patas de la mesa, juntan las patas con la mesa" (Est.03). Además, un alumno logra identificar la función mecánica de una parte de la mesa que, en un primer momento, no sabía nombrar, "...esa cosa rara, su función es aguantar la mesa…" (Est.04).

Posteriormente, en la fase *síntesis*, identifican como las partes trabajan juntas para constituir la unidad del objeto mesa. Una vez realizado el diseño de la mesa (conciencia de los elementos que la constituyen), movilizan conocimientos y habilidades de ingeniería y matemáticas para evaluar un catálogo de materia prima, incorporado a la ficha de trabajo, verificando qué materiales cumplen con los criterios preestablecidos en el reto. Este catálogo tiene opciones de compra de materiales que presentan restricciones contradictorias, que permiten múltiples respuestas según qué atributos se prioricen. Por ejemplo, una mesa que saldría más barata podría estar asociada a mucho desperdicio de material. Por lo tanto, la calidad de la respuesta dependerá de los argumentos utilizados por ellos.

En este proceso, los estudiantes realizan cálculos matemáticos diversos, aplican estrategias propias y habilidades matemáticas, como la representación, para solucionar el problema. En este sentido, es posible agregar algunas observaciones de los estudiantes, que tienen relación con conceptos como identificación del perímetro, comparación de precios, cálculos y estimación. Por ejemplo, "[para] la tabla de madera necesitamos calcular el perímetro de la mesa" (Est.06); "A ver, tampoco es la más barata…" (Est.07); "Tenemos que multiplicar

322 por 10" (Est.08); "Lo que nos sobre lo vendemos. Entonces podemos hacer los cálculos de cuánto cuesta ese trozo y lo vendemos. ¿Puedo hacer los cálculos?" (Est.09). Se ejemplifica el uso de estrategias en la Figura 6, donde el estudiante utiliza la representación para la resolución de problemas.

Figura 6: Niño representado las mesas por medio de rectángulos

Fuente: elaboración propia.

Luego, considerando los criterios pre-establecidos en el reto (medidas idénticas a las mesas, precio conveniente y sostenibilidad), los estudiantes eligen las opciones de madera y tubos, para entonces calcular el presupuesto.

Una vez que el equipo considere haber resuelto el reto, el maestro se acerca y verifica que todos los miembros están de acuerdo y que han comprendido la consigna del reto. Esta fase de gestión del reto se denomina *consolidación* y se "considera resuelto cuando todos los miembros del grupo están de acuerdo con la(s) solución(es) obtenida(s)" (PERDOMO-DÍAZ; FELMER, 2017, p.432).

3.3.4 Fase de cierre: argumentación sobre el diseño de ingeniería (20 minutos):

Una vez que los estudiantes concluyen su propuesta de diseño, cada integrante del equipo aporta un argumento de las decisiones tomadas. De esta forma, se elabora una argumentación consensuada que explica su diseño según la premisa: dimensión, precio y sostenibilidad. Finalmente, se implementa el último momento de la gestión del reto, la *discusión*, en ella el alumno cuyo rol es portavoz o coordinador, presenta el diseño y argumento para toda la clase.

Entre los argumentos aportados por los estudiantes, podemos destacar algunos en los cuales manifiestan estrategias de uso de los residuos, por ejemplo:

"elegimos la [opción de madera] D, porque cada cinco tablas de D, con los restos podemos hacer otra. En tubos, tomaremos siete de la [opción de tubo] A y como nos queda tubo, los trozos los usamos para otra mesa" (Est.10). En esta respuesta, se evidencia el manejo de unidades cuadradas como precursor del concepto de área, que aún no había sido formalizada. Por otro lado, si bien la respuesta escorrecta matemáticamente y cumple con los criterios, la estrategia implicaría múltiples soldaduras para unir cada segmento de tubo. Esto es económicamente inviable; además, la estructura de la mesa tendría baja resistencia mecánica y sería poco estética.

En cambio, otro grupo toma la decisión de unir los sobrantes de madera para la construcción de la décima mesa para, de esta forma, ser más sostenibles y rentables, pero sin olvidar la estética. Ellos argumentan: "[elegimos la opción de madera] D, porque compramos 9 y nos sobran 9 partes. Nos da una mesa y nos sobran tres partes. Hacemos una mesa con esas partes y ya tenemos las 10 [mesas]. Le vamos a poner una capa fina para que no se vean las uniones" (Est.04). Esto evidencia que los alumnos relacionan el cálculo matemático con su significado físico. Ellos son conscientes de que la suma de las partes de madera genera una mesa con discontinuidad de la superficie.

En lugar de usar los restos para la fabricación de una mesa, también se ha observado la estrategia de venderlos para recuperar el dinero: "hemos elegido la [opción de madera] B porque entra en la medida [requerida] y nos sobra diez [unidades cuadradas] y lo vamos a recortar y nos saldría más barato. Lo que sobra lo vendemos en dos euros. El metal es [la opción] A y como nos sobran 110 cm, lo venderemos por 29 euros. Es sostenible porque no gastamos mucho y lo que nos sobra lo vendemos" (Est.11). En esta respuesta, es posible observar que han calculado el precio proporcional por cumplimento y por unidades cuadradas. Durante la presentación de argumentos, también surgen elementos éticos en la discusión sobre precio – sostenibilidad. Ante ello, un grupo declara: "hemos decidido que es mejor ser sostenible que económico" (Est.05).

3.4 Evaluación de la actividad

El diseño e implementación de la actividad *Ingeniería inversa de una mesa* ha sido evaluada de acuerdo a los criterios del modelo de calidad de enseñanza de ingeniería en la educación básica propuesto por Moore *et al*. (2014). En este sentido, se describen algunos resultados respecto a cada criterio.

Proceso de diseño: este aspecto es central en la actividad que se desarrolla en torno a la ingeniería inversa, en el que el alumnado visualiza el proceso de diseño de manera retrospectiva, de lo concreto a lo abstracto, del producto hasta su diseño.

Concepciones sobre el área y la profesión de ingeniería: al inicio de la actividad se aclara brevemente que es la ingeniería. Sin embargo, idealmente, los estudiantes deben participar en actividades dedicadas a profundizar esta conceptualización y desarrollar ideas no estereotipadas sobre la ingeniería (SILVA-HORMAZÁBAL; RODRIGUES-SILVA; ALSINA, 2022).

Herramientas: la actividad permite que los estudiantes manipulen herramientas de medición (metrología), tales como la cinta métrica. El contexto auténtico provoca la necesidad de utilizar estas herramientas, por lo que cobra sentido para el estudiante.

Aplicación de conocimientos de otras disciplinas: la actividad gestiona la identificación autónoma y la utilización de conocimientos matemáticos previos implicados en el contexto del problema. Si bien la propuesta no introduce conocimientos matemáticos nuevos, permite el desarrollo de competencias matemáticas en conexión con la ingeniería y la vida real.

Ética: se verifica este indicador principalmente en el momento en que los estudiantes deben tomar decisiones de sostenibilidad en el diseño de su propuesta. En este caso, suceden diversas situaciones, algunos olvidan este requisito y se centran inicialmente en que el precio sea el más conveniente. Mientras, otros deciden priorizar la preocupación ambiental en relación al precio.

Trabajo en equipo: la organización de los integrantes de los equipos por roles ha permitido definir responsabilidades, pero también desarrollar el sentido que el trabajo individual favorece el bien común del grupo. Además, el hecho de que todos los integrantes debían estar de acuerdo con los resultados o propuestas, permite velar que colaboren y estén involucrados en las decisiones.

Comunicación: si bien este indicador se potenció durante el transcurso de la actividad, toma mayor realce en el momento de cierre, ya que es cuando deben da a conocer sus propuestas y argumentar sus decisiones. La comunicación es un factor clave, ya que el desafío permite múltiples respuestas y la calidad de la respuesta se mide a través de la argumentación de las ideas, en función del cumplimiento de los tres requerimientos de la actividad.

4 Consideraciones finales

En este artículo se ha presentado el diseño, implementación y evaluación de una actividad STEAM en educación primaria, a partir de la interdisciplinariedad entre la ingeniería y las matemáticas. Este objetivo responde a la necesidad de apoyar al profesorado en un área que está siendo recientemente incorporada a la educación primaria, lo cual supone un desafío para el docente (KIM; BOLGER, 2017).

En específico, se ha identificado que la actividad descrita permite el aprendizaje de conocimientos matemáticos, tales como nociones geométricas (unidades cuadradas y perímetro), medición y operaciones. Los participantes han mostrado conciencia de la relación entre operaciones y sus significados físicos. Por ejemplo, cuando suman unidades cuadradas de madera, pero sabiendo que esto se traduciría en discontinuidad de la superficie de la mesa. Además, se ha observado el desarrollo de habilidades de representación y resolución de problemas.

Respecto a la ingeniería inversa, los estudiantes han explorado la mesa en detalle y han logrado identificar sus componentes, la función de cada uno y los elementos de unión. Además, han desarrollado estrategias de diseño, sobre todo en la selección de materiales en un catálogo con condiciones restrictivas de medidas, precio y sostenibilidad. Este proceso pone en juego habilidades de resolución de problemas, creatividad y pensamiento crítico y ética. La argumentación final moviliza competencias de sostenibilidad y de ciudadanía para la adopción de estilos de vida sostenibles, lo cual va en directa relación con el actual marco regulatorio de la educación en España (MEFP, 2022) y la EDS (UNESCO, 2017).

Por último, las características descritas y el análisis de los criterios de calidad (MOORE *et al*, 2014) nos permite recomendar la replicación y adaptación de la experiencia a otros contextos, así como también, la ampliación a otras conexiones intra e interdisciplinarias. La simplicidad y riqueza de la actividad posibilita al profesorado contrastar la percepción de que la enseñanza de la ingeniería no está limitada a actividades complejas y costosas (HAMMACK; VO, 2019). Por último, se sugiere al profesorado, ampliar la actividad didáctica realizando reflexiones que retomen los episodios centrales de la experiencia presentada. Así como también, profundizar en los contenidos disciplinares emergentes, haciendo énfasis en las conexiones interdisciplinares y los aportes de cada área del acrónimo STEAM (RODRIGUES-SILVA; ALSINA, 2023).

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Sobre os autores

Jefferson Rodrigues-Silva
Graduado e mestre em Engenharia Mecânica (UFSJ). Especialista em Segurança do Trabalho (FAVENI). Doutorando em Educação pela Universidade de Girona (UdG). Professor efetivo do Departamento de Engenharia Mecânica do Instituto Federal de Minas Gerais (IFMG) *Campus* Arcos. Membro do Grupo de Pesquisa em Educação Científica e Ambiental (GRECA). Linhas de pesquisa centradas na educação STEAM, na engenharia em idade escolar e na formação de professores.
Currículo Lattes: http://lattes.cnpq.br/0246316357702468

Marcela Silva-Hormazábal
Graduada em Educação pela Universidade dos Lagos (ULA), mestra em Educação pela Universidade de Concepción (UDEC). Doutoranda em Educação pela Universidade de Girona (UdG). Professora efetiva do Departamento de Especialidades Pedagógicas da Universidade Austral de Chile (UACh). Membra do Grupo de Pesquisa em Educação Científica e Ambiental (GRECA). Pesquisa centradas na educação matemática nas primeiras idades e na formação de professores de matemática do Ensino Fundamental.
Orcid: https://orcid.org/0000-0002-1955-1633

Ángel Alsina
Doutor em Psicologia pela Universidade Autônoma de Barcelona (UAB). Professor titular do Departamento de Didática das Matemáticas da Universidade de Girona (UdG). Investigador Principal do Grupo de Pesquisa em Educação Científica e Ambiental (GRECA). Linhas de pesquisa centradas no ensino e aprendizagem da matemática desde a infância e na formação de professores.
Orcid: https://orcid.org/0000-0001-8506-1838

Acceptance proof

Gmail **Jefferson Rodrigues-Silva <jeffe.rodri@gmail.com>**

[PDE] Decisão editorial

Portal de Periódicos UFJF <noreply.periodicos@ufjf.br> 30 de junho de 2023 às 23:46
Responder a: "Prof. Dr. Frederico Braida" <frederico.braida@arquitetura.ufjf.br>
Para: Jefferson Rodrigues-Silva <jeffe.rodri@gmail.com>, Marcela Silva-Hormazábal <marcela.silva@uach.cl>, Ángel Alsina <angel.alsina@udg.edu>

Jefferson Rodrigues-Silva, Marcela Silva-Hormazábal, Ángel Alsina:

Nós chegamos a uma decisão referente a sua submissão para o periódico Pesquisa e Debate em Educação, "Colocando a engenharia sobre a mesa: uma atividade STEAM de engenharia reversa e matemática".

Nossa decisão é de: Aceitar a Submissão

Em breve, seu artigo estará publicado.

Atenciosamente,

Equipe Editorial

Revista Pesquisa e Debate em Educação

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ARTICLE 9

STEAM and theatrical education

When engineering students play a role

Rodrigues-Silva, J., & Alsina, Á. (In submission). STEAM and theatrical education: When engineering students play a role.

STEAM and theatrical education: when engineering students play a role

STEAM e educação teatral: quando estudantes de engenharia assumem um papel

Jefferson Rodrigues-Silva, Ángel Alsina

Abstract: Eleven mechanical engineering students participated in a STEAM (interdisciplinarity between Science, technology, engineering, Arts/Humanities, and Mathematics) drama activity of conceiving and performing a play which addressed their course. Following, we pursued a Thick Description of this project, including the meanings and intentions of the play. Accordingly, we interviewed the students so that this description could reflect their voices. As a result, we observed that the drama activity permitted learning about engineering and theatre. Moreover, it was a space to contrast the ideal and the real engineering toward society and to call students to play the role of subjects responsible for their personal, professional and political lives.

Keywords: Augusto Boal; Engineering; Subject-ness; STEAM education; Theatre of Oppressed.

Resumo: Onze estudantes de engenharia mecânica participaram de um projeto STEAM (interdisciplinaridade entre Ciência, Tecnologia, Engenharia, Artes/Humanidades e Matemática) a partir de uma atividade teatral de concepção e encenação de uma peça sobre seu próprio curso. Ao respeito, realizou-se uma Descrição Densa desse projeto, incluindo os significados e intenções da peça. Nesse sentido, entrevistaram-se os alunos para que essa descrição pudesse refletir suas vozes. Como resultado, observou-se que o a atividade permitiu aprender sobre engenharia e teatro. Além disso, foi um espaço para contrastar a engenharia ideal e real perante a sociedade e chamar os alunos para o papel de sujeitos responsáveis por suas vidas pessoais, profissionais e políticas.

Palavras-chave: Augusto Boal; Engenharia; Subjetificação; Educação STEAM; Teatro do Oprimido.

1 Introduction: How theatre entered a mechanical engineering course?

This article reports a theatrical experience in higher education in the Brazilian city of Arcos. A city that recently celebrated opening a Federal Institute of Minas Gerais (IFMG) campus, offering a single course—mechanical engineering bachelor.

Arcos is a small city with less than two square miles of an urbanised area that stands out from its several limestone mining companies. Whereas limestone companies develop surrounding this community, arts and culture, seem to be relatively forgotten. The city has been waiting for a new cinema for years since the old one was closed.

In this context, a mechanical engineering teacher (the article's first author) felt a call of responsibility to promote artistic activities according to his possibilities. Subsequently, he created the Engineering & Arts project, where different creative activities took place: a dance company performance addressing women in engineering, a mosaic workshop with primary school students, and an art exposition with mosaics about mechanical engineering (RODRIGUES-SILVA *et al.*, 2018).

Besides those activities were initially understood as modest gestures, they seemed to have impacted this community somehow. Donizetti Bernardes—an experimental actor and theatre director— heard about those initiatives and came up with an idea. Thus, on 2nd August 2019, he proposed a partnership with this professor for a drama activity.

That day, the Engineering & Theatre project was born: a four-month project where students would engage in group discussions about engineering and theatre, participate in theatrical laboratories, and then conceive and perform a play which addressed mechanical engineering. All this planning followed was theoretically scaffold in STEAM education, an educational approach which refers to the interdisciplinary teaching between science, technology, engineering, arts/humanities, and mathematics (PERIGNAT; KATZ-BUONINCONTRO, 2019; RODRIGUES-SILVA; ALSINA, 2023a). The acronym STEAM was created in 2007 at a roundtable in the United States as an opposite movement of STEM education, whose efforts and investments privileged the technical areas of science, technology, engineering, and mathematics (CATTERALL, 2017).

Besides this inclusion of arts and humanities, STEAM is commonly criticised for a utilitarian approach by attributing a subservient role to arts and humanities regarding the technical ones (CHESKY; WOLFMEYER, 2015; MEJIAS *et al.*, 2021). In this direction, STEAM is frequently reported as a neoliberal pedagogy concerned only with *qualification*: where education is reduced to nurturing knowledge and skills the twenty-first-century society seems to require (BIESTA, 2020; KETTLE *et al.*, 2023). However, literature also shows that STEAM is suitable for addressing sustainable issues (GUYOTTE, 2020; RODRIGUES-SILVA; ALSINA, 2023c), such as the pursuit of gender equity (SILVA-HORMAZÁBAL; RODRIGUES-SILVA; ALSINA, 2022), food literacy (SILVA-HORMAZÁBAL *et al.*, 2022).

Moreover, STEAM may enhance students' attitudes towards science (CARRASQUILLA; SAN ROQUE; PASCUAL, 2023), and performance is a powerful language to address and develop science (PARRY, 2020). For instance, it shows drama reported on experiences involving AIDS (ALMEIDA *et al.*, 2021), science museum performances about robots (PELEG; BARAM-TSABARI, 2017) and prevention of scientific denial theories such as flat earth (FRANÇA *et al.*, 2021).

Accordingly, we were confident about the feasibility of creating a dense and overwhelming STEAM experience through the connexion between engineering and arts. For that, we should always remain vigilant that both knowledge areas have a value de *per si and* must evenly beneficiate from each other (MEJIAS *et al.*, 2021). Moreover, we directed our efforts to reach educational purposes other than *qualification* (acquiring knowledge and skills). The drama activity intends for students' *socialisation,* which means introducing them, in this case, to cultures of artistic and engineering communities.

Studies evidenced that children from a very early age tend to conceive engineering as a manual activity, developed individually, in fieldwork and destined for men (RODRIGUES-SILVA; ALSINA, 2023d, 2023e; VO; HAMMACK, 2022). In this regard, reflecting and presenting engineering to the community is vital in overcoming stereotyped conceptions of this profession. Simultaneously, this activity should provide students with a personal space where they could, using Boal's Theatre of Oppressed terms, express themselves, study their realities and change it (KINA; FERNANDES, 2017). Furthermore, the project aimed to call students *subject-ness* (which is different from subjectivity); in other words, *subjectification* refers to their autonomy as subjects who decide to embrace (or not) ethical dilemmas and responsibilities of their actions that they will encounter in their personal, professional, and political lives (BIESTA, 2020; MARTINS; RODRIGUES-SILVA, 2022).

Considering all that, we pursued a Thick Description of the Engineering & theatre project, including the meanings and intentions of the play.

2 The Engineering & theatre project

First, we consulted the institutional project archives and found no registers of theatrical activities, which means those students had not had similar experiences on this campus before. At this moment, 131 students were regularly enrolled in the mechanical engineering course, 110 males and 21 females, according to the Office of academic records. We invited all students from this course, and eleven (8.4%) showed interest in participating in the project.

All interested students were accepted into the project as volunteers. Those students firmed consent authorisation to use their images and productions for research purposes. Regarding their gender proportion, we should remark that it was inverted in the project compared to the course's general distribution, so women became the majority, six females and five males. We will further address this aspect later.

We pursued the qualitative methodology of a Thick Description, defended as a good form of understanding people and peoples' self-understanding within a specific context (THOLEN, 2018). Hence, at the end of the project, seven students participated in a semi-structured interview. Those interviews were recorded, transcribed, and then analysed through multiple comparisons. We addressed the issues that emerged from the data so that this description reflected students' voices. We identified the students with fictitious names to ensure their anonymity according to their opinions.

We start describing the preparation sessions, which were dedicated theatrical laboratories and three cycles of reflections: Connections between engineering and theatre, Engineering from what you eat to what you shit, the history of theatre, and the aesthetic method of the Theatre of the Oppressed (TO). Following, we describe the creational process of writing the play. Then we focus the description of the play on its three acts. Lastly, we address educational outcomes, and we make some final considerations.

3 Connections between engineering and theatre: Let's think about it

The STEAM project had one apparent demand: conceiving and performing a play which addresses mechanical engineering. Ana, one of the students, commented that this proposal awakened a state of reflexivity. According to her, "from the first group meetings, everyone had an interrogation: what will the text be? What do we want to talk about in the play?"

Accordingly, the initial sessions were dedicated to discussion circles. In the first discussion cycle, students to reflect on their prior conceptions, expectations and feelings regarding the interdisciplinary approach to engineering and theatre. This discussion was vital because the drama was new to them and, as Daniel emphasised, the junction with engineering caused oddity at first sight:

> People find the relationship between theatre and engineering weird because they have prejudice. For them, those who do theatre are not responsible people. In the beginning, we also saw the theatre as something disconnected: why engineering and theatre? But when you zoom in, you start to see that the two have a lot in common.

For Bernardo, the prejudice about theatre comes from a lack of knowledge, "there is still prejudice and shame in participating in theatre because it is unknown in our environment [the mechanical engineering course]. You have to participate to see what theatre is like." Gender differences are addressed when another student hypothesises criticism, and mockery may have discouraged some boys from participating in the project. "Men take longer to develop maturity, and many are ashamed. They fear being mocked by their colleagues. So our group had more women than men: we did not care much about others' opinions" Bianca.

Fortunately, the project helped those students (and perhaps the audience) deconstruct some of those misconceptions and gender stereotypes. Daniel says, "While participating in the project, I realised how theatre is fascinating and can offer countless opportunities." Ana initially expects male students not to participate in theatre activities. "I was even surprised about the number of men participating in the play because I expected it to be less". Nevertheless, she comments that the contact of engineering students as spectators of the theatre may have had some effect in this aspect on prejudices about theatre that may have prevented men from participating, "everyone was amazed by the theatre, and I think it ended up breaking that barrier for some. I think that if the project continues, more men will enrol."

In a second session, the students investigated the history of theatre and the aesthetic method of the Theatre of the Oppressed (TO), created by Brazilian playwright Augusto Boal (KINA; FERNANDES, 2017). Then they shared that information about theatre and drama. Moreover, Donizetti (experimental actor and play director) deepened the discussion about theatre in this session and throughout the project. We clarified to the students that arts and engineering should be evenly addressed in the project. We also highlighted that one knowledge area should not be reduced into an instrument to convey the other (MEJIAS *et al.*, 2021; RODRIGUES-SILVA; ALSINA, 2023a).

In the third section, we focused on the reflection on engineering. We provided the students with two videos about the fabrication process of spoons and ceramic toilets. Afterwards, they used that information to ignite the discussion "Engineering from what you eat to what you shit". During this conversation, the students highlighted the presence of this discipline in every aspect of contemporary human life. Interestingly, despite being engineering students, some remarked they usually do not think about their course from broader perspectives, such as its presence and imbricated relation to society.

In subsequent sessions, we developed theatrical laboratories with the students: improvisation, perception, hearing, and vision, or in Daniel's voice, "we did a series of dynamics to develop group trust." Through this comment, we may infer that this student's memory was captivated by an activity devoted to developing group trust. As shown in Figure 1, students were blindfolded and relied on their fellowship in an exploration journey around the campus.

Figure 1 – Blindfolded students during an activity of group trust

Source: Project archives. Photography of Cláudia Borges Coelho.

Addressing their prior conceptions and deepening their knowledge about engineering and theatre was crucial to construct a shared vision of engineering, theatre, and the engineering-theatre junction. Additionally, this preparation intended to make the project proposal meaningful to them. Altogether, those discussion cycles and laboratories prepared them for the subsequent activities within the project: playwriting, scenario conception, rehearsals, and the play performance.

4 Writing a script: we are about to have a play!

We supported students with writing the play, but they had significant autonomy in this process since addressing mechanical engineering remains a somewhat open arena. Accordingly, students were aware of this autonomy and embraced this responsibility and ownership during text conception. In this sense, Roberto says, “it was anything imposed. We always discussed when we thought something should be changed. We could do it because the text was ours”.

They also have the freedom to develop their strategies for writing the script. Ana explains that they initially deepened into more research “we started researching texts that portrayed engineering in everyday life. We looked for information about the evolutionary history of technology development to determine the sequence of the text according to the chronology of the inventions”. Another student comments on how they focused their work on the mechanical engineering course: “We always tried to cover as much as possible within the area of mechanical engineering, which is the course we take, and then develop the play.” Daniel.

After they gathered information, they started writing the play. Daniel reports positive feelings regarding this phase. As another strategy, he explains that they created an initial text as a base, “the beginning of the text production was exciting. We created scenes, and keywords appeared in the middle of those scenes, giving a structure to the text, a base.” The student completed the explanation with a second writing stage in which they enriched and refined the text, “after we created this base, we added more content related to engineering throughout some keywords to give more fluidity to the text.”

We may refer to a safe and trustworthy space to share opinions and work collaboratively (URIA-IRIARTE, 2021). Daniel emphasises the enthusiasm and collaborative work of writing the play. For example, when they independently scheduled additional meetings: “we got together to see how the text was evolving. We even had some extra meetings to talk about the play". In addition, students' interviews evidenced that they adopted a democratic posture. For instance, Ana commented they had discussions until they had a consensus and approval of the text. "Among all students, we gathered ideas and opinions until we reached a final text. We approved it when we all accepted that it was sound and transmitting the message we wanted. Moreover, Bianca highlights the respect for different opinions in those meetings "the atmosphere of work allowed us to have different opinions from each other."

After all that collaborative writing, they finally have a play script! So now we describe the play, whereas we expand considerations such as scenario conception and the rehearsals. Starting from the play's name, the participants called it "*Integrados*" –translated as "integrated" from Portuguese – because of a triad of meanings of this word in its original idiom. The students explained that the name broadly expresses the integration of engineering and theatre; second, the idea of integrating engineers into society emerges. In addition, *"Integrados"* also alludes to the mathematical operation of integrals, which is highly representative of engineering calculations.

From an intimate perspective, *"Integrados"* also referred to interpersonal relationships since they felt a strong connection with each other; For instance, they decided to create a T-shirt to celebrate and create an identity as a group. Related to the collaborative working, Ana remarks surprise, "I did not expect such a nice interaction in the group. Everyone in the project was trying their best." Likewise, Santos says, "I developed a quite strong relationship with my colleagues and instructors. We constructed friendships that go beyond the theatre."

Once they had chosen the play's name, they settled on its performance date: 7th November 2020; the big day was coming! In order to disclose it, we sent an open invitation to the internal community of the campus (students, professors and university staff) and the external community (students' families, friends and any people interested). Now on, we describe the play and its three acts: 1) We are not robots, are we?; 2) Guilty Conscience; and 3) Graduation ceremony.

4.1 First act: We are not robots, are we?

Staging awaited the public with a robotic ambience. As Ana explains, "the play starts with some students wrapped in aluminum foil in a static position." In Figure 2, we can observe how students cover each other with aluminum foil during a rehearsal.

Figure 2 – Mechanical engineering students wrapped in aluminum foil to address the misconception of engineers as robots

Source: Project archives. Photography of Cláudia Borges Coelho.

Ana continues describing that “while the audience enters, it sounded a robotic music ambience.” The robotic music that this student mentions is the song *Die Roboterm* (The Robots in English) from the German band *Kraftwerk*. It is a single that provides robotic imagery through repetitive refrains, pitched voices and electronic notes. In addition to the robotic atmosphere, students choose it because the song discusses the subservient roles between robots and humans.

Moreover, they conceived a scenario to immerse the actors and the audience in a world built on machines. As Bernardo explains, “the scenario focused on the engineering course. It had several bicycle rims, tools, and other machine mechanisms.” Carla remarks, “The scenario we created was impressive. I observed the audience astonished from the stage entrance.” In Figure 3, we can observe an element from the scenario made up of cords and bicycle rims.

Figure 3 – Element from the scenario constructed with bicycle components

Source: Project archives. Photography of Cláudia Borges Coelho.

After the audience arrived and settled down, a student started dramatising a text that addresses the Greek myth of Prometheus and Epimetheus concerning the origin of humankind. The legend says the Gods charged the brothers to distribute skills and goods among the animals, such as force, speed, and wings. At the end of the distribution, Epimetheus perceived he had forgotten the man, who was fragile and could not defend himself from the beasts. Therefore, Prometheus stole the fire of technique from Olympus and gave it to men. This fire represents men's intelligence to adapt and transform the environment to survive. In the play, students remarked that this fire represents engineering and its technological development, or in Ana's words, "we presented the Prometheus myth bringing the engineering until today."

In the sequence, the play reports that humans created machines, but at some point, men became so dependent and overshadowed by their glow that humanity was now at risk of technological servitude. Bernardo explains, "we criticised that machines are replacing man, leaving him behind, now machines do everything. Through this criticism, we try to alert that this should not happen. The man is the one who needs to be on command." Figure 4 shows how the students created a worship scene for the machines. In this scene, some were kneeling while praying to the robotic figures.

Figure 4 – Rehearsal of the scene of worship for the machines.

Source: Project archives. Photography of Cláudia Borges Coelho.

During this worship, the group on their knees said things men used to do, whereas the robots answered that now the machine does such things. As is illustrated in the following fragment:

> Men ploughed. Machines do!
> Men harvested. Machines do!
> Men fought. Machines do!
> Men killed. Machines do!
> Men healed. Machines do!
> Everything men did? Machines do!
> Zero hours. Machine, pray for us!

Roberto made an exciting lecture that goes beyond the message of humanity and technological servitude and addresses psychological healthy. He criticises the current social pressure of being productive all the time. For him, the theatre was a temporal space that permitted him to see engineering differently and, by extension, escape from the bubble of this course to see an outside world. In his own words:

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> When people become machines, they focus on studying or being productive 100% of the time. They end up forgetting about their principles. Then comes psychological diseases: depression, anxiety, and panic syndrome. The theatre project helps significantly in this matter. It represents a moment of distress to see engineering in another way. The play showed us a world outside the bubble of our course.

A character of another student interrupts the worship by warning about the role of engineering for man's welfare instead of servitude to machines. They suddenly break free from the technological illusion. This awareness is physically expressed with them stripping from the robotic covering and assuming their humanity. As Roberto explains, "we started as machines. Then you have a shock of reality. We are not machines, and we have human values! As engineers, we should superimpose ourselves above the machine." This first act is strong evidence that the drama activity called students to recognise themselves as subjects. Biesta (2020) defends that *subjectification* is an essential and frequently forgotten purpose of education. Since they are not robots (objects) but subjects, they are called to take responsibility in the world. However, as subjects, they decide to take or not on those responsibilities—this *subject-ness* leads to ethical dilemmas and consciousness as a self. That is furthered in the play's second act.

4.2 Second act: The "Consciência Pesada" (Guilty Conscience)

Ethical concerns brutally cross those students from the eruption of *subject-ness*. The character *"Consciência Pesada"* (Guilty Conscience) enters the stage, pointing out a series of inappropriate behaviors of these students, such as dishonesty and arrogance.

> You cheated on the test! You mocked your colleagues who failed thermodynamics. You transformed your parents' money into beers instead of buying those supposed books.

Regarding this episode, Santos clarifies that they intended to portray their agonies within the course. In this sense, the Guilty Conscience represented those regretful feelings mixed with the pressure and willingness to succeed: "The text also shows our struggles within mechanical engineering, which is a difficult course. The text shows our feelings when we fail in a discipline, and we think: why haven "t we studied more? Why not seek more information resources to succeed in the discipline?"

"Consciência Pesada" means literally heavy Conscience in Portuguese. Accordingly, the students had idealised a costume for this character as a heavy/big person, alluding to the weight. However, the girl who would play this character felt uncomfortable

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doing it that way. In this specific case, the student had her subjectivity respected by changing the representation of this character. Roberto explains:

> Regarding the appearance of Guilty Conscience, Carla changed its clothing. In the end, she incarnated the character and played a perfect role. The play's main character, or at least the one that caught the most attention, in my opinion.

The physical reference to weight was replaced by an obscure and mysterious outlook. The student who acted this character proposed wearing formal shoes, a long dress and a mask. Then she contrasted the dark clothing of Guilty Conscience with a bright object which clearly referred to a brain, as shown in Figure 5.

Figure 5 – Guilty Conscience character holding a brain

Source: Project archives. Photography of Cláudia Borges Coelho.

Continuing the play description, after making accusations of students' antithetical behavior, Guilty Conscience decided to sit in a chair, which in this case, represented all engineering products. Roberto remembers, “the Guilty Conscience was going to sit in a chair; then we said the chair could not support it because she was too heavy.” At this moment, several mathematical and engineering concepts emerged, as evidenced following fragment:

> Guilty Conscience: I will sit down and get some rest. The Conscience of this class is too heavy!
> All: No!
> Ana (pulls back chair): Don’t get me wrong, but this chair might not support you. Let me say your center of gravity is a little off.
> Guilty Conscience (takes back the chair): my center of gravity is very well located, thanks.
> Roberto: Not wanting to be intrusive, but given the dimensions, maybe just X, Y, and Z axes are not enough to locate it.

Regarding this fragment, Bianca comments that “there was a part of the theatre where we talked about the center of mass and made a joke about coordinates: that only the x, y and z axes were not enough to find the center of mass of Guilty Conscience because it was cumbersome. She explains, “this axis that Roberto did has to do with the fact that Guilty Conscience was heavy. I think the people watching understood the message we wanted to communicate.”

After Guilty Conscience argued with the students, she finally sat on the chair. After a while, students showed her the engineering goods, such as shoes, textile manufacturing, and airplanes, as shown in Figure 6. Concerning this scene, Ana remarks, “the main message we wanted to convey in the play was that engineering is present in everything in our lives.” This part of the play was probably influenced by the discussion cycle “Engineering from what you eat to what you shit”.

Figure 6 – A student hands a blanket to Guilty Conscience

Source: Project archives. Photography of Cláudia Borges Coelho.

Nevertheless, Guilty Conscience counter-argued those benefits of engineering with another side that accompanies engineering, and that may harm society. This part of the play frames Boal's encouragement in Theatre of Oppressed to create images of the *real* and *ideal* (KINA; FERNANDES, 2017). As demonstrated in the fragment below, there is a contrast between ideal and real engineering:

> Student: Engineering makes shoes to protect our feet!
> Guilty Conscience: Engineering makes bombs and has nowhere to run.
> Student: Textile manufacturing provides clothing to protect us from the cold.
> Guilty Conscience: Clothing does not protect you from bombs.
> Student: Engineering made airplanes.
> Guilty Conscience: Well, you are right. I like airplanes, such a formidable invention! I call them "bomb launchers".

At this point, it is noteworthy to say that the example of the airplane is quite emblematic for Brazilians. This country attributes the Brazilian Santos Dumont the title of inventor of the airplane. Dumont fell into a deep depression and committed suicide to the agony of seeing his invention being used to kill people in wars (OLIVEIRA, 2022).

As stated before, this second act signs students' *subjectification* process as an educational outcome of the drama activity (BIESTA, 2020). The character of Guilty

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conscience remarks on the existence of a subject that takes (or refuses to make) decisions in the middle of contrasting ideas of engineering.

4.3 Third act: Graduation ceremony

Once students have emerged from their humanity, faced the Guilty Conscience, and reflected on ideal and real engineering contrast with its benefits and harm to society. In this third act, students cover Guilty Conscience with black cloth. Then, the students wear graduation gowns and take the engineering oath – a symbolic element which remarks their integration into society under the identity of a sound engineer, as shown in Figure 7.

Figure 7 – Students take the engineering oath with a coved, but always present, Guilty Conscience

Source: Project archives. Photography of Cláudia Borges Coelho.

While they promise to be good professionals, one student recites the oath with a hand over Guilty Conscience's head. After all, she may be coved, but she is still present.
The oath is transcribed below.

> I promise that, in fulfilling my duty as an engineer, I will not let myself be blinded by the excessive brightness of technology, never forgetting that I work for the good of man and not of the machine. I will respect nature and avoid designing or building equipment that pollutes or destroys the ecological balance. I will put all my

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> scientific knowledge at the service of the comfort and development of humanity. So I will be at peace with myself and with God.

This part of the play was particularly emotional to the students participating in the project, and we risk saying it might also substantially impact those students from the audience. Ana states:

> The dream of everyone in an undergraduate course is to conclude it. The graduation ceremony is the culmination of that. What impressed us the most was imagining ourselves wearing that gown and taking an oath that we did not even know existed. I discovered it in the play.

Moreover, we should pinpoint that the oath is intrinsically related to the purpose domain of education of *socialisation*, which means being introduced to society or a culture of community, a professional community in this case (BIESTA, 2020). Since students reported that one intention of the play was to present engineering to society, in this sense, the play responds again to the educational purpose of *socialisation* if we consider the audience.

Once the students have taken the oath, the play finishes with everyone choring "Some people see how things are in the world and ask –why? Engineers dream with things that do not exist and wonder –why not?"

5 Educational outcomes

Throughout the description of the play, we have remarked on educational outcomes related to *subjectification* and *socialisation*. Following, we focus on another domain of educational purposes: *qualification*, so we address the outcomes of the drama activity regarding content knowledge and skills development (BIESTA, 2020).

5.1 Content knowledge

We identified that some were motivated to participate in the project to learn from new areas, indicating they were open to learning about theatre in this particular case. Bianca says, "I decided to participate in the project to bring knowledge from new areas, subjects that would probably not be available in the classroom". In this sense, we can affirm that the project reached such expectations because they were taught about things they would not have the opportunity otherwise, for instance, historical and methodological aspects of theatre. Specifically, Santos reports overcoming difficulties and acquiring skills in the theatre which might help him in future engineering studies, "for me, memorising the text for the theatre was a hard job. An ability which will be important for studying following engineering disciplines."

At the same time that the drama activity brought knowledge from new areas, it also instigated the deepening of engineering concepts. In this sense, Roberto explains, "I had many speeches about engineering. So I should know those concepts in-depth to present them appropriately in the play. For example, the meaning of the centre of mass is" Roberto said. Bianca corroborates this idea, "we spoke about several topics related to materials stiffness, such as tensions and deflection. Many other technical terms".

For several moments, students showed concern in approaching engineering concepts so that an audience of non-engineers could understand them. "The play involved the technical concepts in a way that everyone could understand", Bernardo said. Furthermore, they demonstrated awareness of the complexity of the concepts addressed. "Our theatre had terms that perhaps only an engineer could know. However, as we aimed at our public, we did more explanation to bring these concepts to lay people as well," Daniel. They even explained some strategies to make engineering concepts accessible to the public, "since the rehearsals, I noticed that Roberto was gesturing so that the spectators from the theatre would understand the centre of mass. Maybe they did not have much engineering knowledge, so these movements presenting the axes with his hands and arms helped people understand what we were talking about." Ana.

Bernardo further relates this attention to a public understanding as a communication skill required in engineering: "A good engineer has to know how to listen and speak. Explain solutions to problems in a way that others will understand." In sum, the educational outcomes reinforce that STEAM education can be approached by playful pedagogies in higher education (RODRIGUES-SILVA; ALSINA, 2023b).

5.2 Disinhibiting and oratory

Roberto reported that fear and shyness in public speaking might have prevented many students from enrolling in the project. He says, "I was so excited to participate in the project that I invited some friends to participate as well. They did not accept it because of their shyness, fear of interacting and presenting to an unknown public."

However, other students faced this fear. Among those students who participated, disinhibiting and oratory was the primary motivation. Roberto comments, "I was afraid to present myself in public presentations. I decided to participate in the theatre to develop this

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skill." Bernardo says, "The motivation to participate [in the theatre] was mainly about helping to speak in public because I am timid sometimes."

Ultimately, they indicated satisfaction concerning disinhibiting and speaking in public development. Santos, for example, was specific by identifying an initial difficulty in stuttering during speeches "the theatre was perfect for my diction. It helped me a lot in my speech. At the beginning of the course, I stuttered in presentations". Bernardo reports improving his self-expression and confidence in defending his opinions. "I used to be reticent. I saw the wrong things and omitted myself. I could not express and defend my opinion about things." Bernardo said.

Roberto emphasised that he started the project focusing on oratory but was surprised by his personal development in other domains. "I started to develop my oratory skills and diction, and I fell in love with that. I liked it a lot more after I was there because it activated my humour side, which I like." Roberto.

5.3 Satisfaction

Students demonstrate high satisfaction throughout the project, e.g., Daniel says, "since the first meeting, I realised the project would be much better than I expected. Others emphasised a great feeling of fulfilment after the performance. "The most satisfying moment for me was after the play performance, the compliments we received." Ana. In this regard, we recall the idea that knowledge of affective nature plays a vital role in transformation of the subject (MAGALHÃES, 2012).

Approximately 50 people watched the play. Regarding the audience's satisfaction, Ana remarks that they liked the play. "I think that the result was overwhelming. Those who watched gave us positive feedback. People loved it and then congratulated us." Bianca.

In tune with the student's satisfaction, they felt motivated to continue the project. For example, Santos says, "I would like to continue the project, so we could explore other fields, provide and expand it." Bernardo further suggests the proposal should be extended to all mechanical engineering students, "I believe that theatre should be for all students in the course." Roberto highlights that the audience supports them to continue "we were highly praised in the end, many teachers were watching our play, and some of them motivated us to continue."

The play was performed only one time. For two reasons, other performances were not possible because of the Covid-19 pandemic, which prevented doing those activities for a significant period. Second, the whole experience of the Engineering & theatre project had an unexpected effect on the mechanical engineering professor, or we could say an aesthetical in his professional development itinerary (PILLOTTO; CAMARGO; GOMES, 2022). He felt incentivised by this interdisciplinary enterprise and started doing a doctorate in education centred on STEAM Education. Therefore, he is momentarily absent from his campus, writing this article, and willing to reactivate the project when he returns to his teaching activities.

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Submission prof

02/07/2023, 18:52 Gmail - [Dialogia] Agradecimento pela Submissão #24694

Gmail **Jefferson Rodrigues-Silva <jeffe.rodri@gmail.com>**

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3 mensagens

Profª Ligia de Carvalho Abões Vercelli <ligia@uni9.pro.br> 15 de junho de 2023 às 14:20
Para: Jefferson Rodrigues-Silva <jeffe.rodri@gmail.com>

Jefferson Rodrigues-Silva,

Agradecemos e certificamos, para os efeitos que se fizerem necessários, a submissão do texto de sua autoria "STEAM and theatrical education: when engineering students play a role", #24694, para Dialogia. Através da interface de administração do sistema, utilizado para a submissão, será possível acompanhar o progresso do documento dentro do processo editorial, bastanto logar no sistema localizado em:

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5. DISCUSIÓN Y CONCLUSIONES[2]

En este capítulo, se interpretan los resultados de la tesis doctoral reflexionando sobre la pregunta de investigación planteada: ¿cómo se puede reconceptualizar STEAM en cuanto enfoque educativo para dilucidar sus objetivos extrínsecos e intrínsecos y sus implicaciones para la enseñanza y la formación docente? Al responderla, se pretende revisar STEAM explorando su carácter distintivo como un enfoque educativo que interactúa con objetivos extrínsecos e intrínsecos de la educación, subrayando al mismo tiempo la enseñanza y la formación del profesorado.

Desde el siguiente orden de ideas, se discutirá 1) cómo se concibe STEAM como enfoque educativo específico e inserido en la educación (OBJ1); 2) cómo STEAM se relaciona con los objetivos extrínsecos e intrínsecos de la educación (OBJ2 y OBJ3); y finalmente, 3) cuáles son las implicaciones de un enfoque STEAM reconceptualizado para la enseñanza y la formación docente (OBJ4 y OBJ5). Aunque los objetivos específicos tienen cierta relación transversal a toda la pregunta de investigación, en paréntesis se indican aquellos objetivos específicos más ligados a cada parte de la pregunta de investigación.

5.1. Un enfoque específico inserido en la educación

En este subapartado se aborda una primera parte de la pregunta de investigación referente a cómo se concibe STEAM en cuanto un enfoque específico e inserido en la educación. Esta indagación es debida a que existen inconsistencias teóricas en STEAM (Ortiz-Revilla et al., 2023) que desvían su conceptualización desde un contexto o desde unas actividades muy particulares. Al respecto, en el Artículo 1 se ha realizado una reflexión sobre lo que es más central de STEAM (Rodrigues-Silva & Alsina, 2023a). Primero, ha sido posible aclarar que STEAM no es una simple evolución de STEM, sino que más bien estos enfoques representan líneas contrarias. Mientras STEAM apuesta por la inclusión de artes y

[2] The Doctoral program requires the thesis to be written in two languages in order to be eligible for an International Doctorate, and therefore this chapter will be written in Spanish.

humanidades, STEM propone la concentración curricular o, como Clements y Sarama (2021) argumentan, cohesión entre áreas técnicas.

En seguida, se ha evidenciado que STEAM no es una metodología de enseñanza y tampoco debería estar limitada a una única manera de enseñar (Rodrigues-Silva & Alsina, 2023a). Al respecto, en la literatura hay estudios de actividades STEAM desarrolladas mediante metodologías de enseñanza situadas en contextos auténticos, como Aprendizaje Basado en Proyectos (ABPj), Aprendizaje Basado en Problemas (ABP) y Espacio *Maker* (del Moral Pérez et al., 2022; Lu et al., 2021; MacDonald et al., 2020). Asimismo, se ha promovido STEAM a través de una enseñanza en contextos imaginados desde el aprendizaje lúdico, como el juego libre, el juego formal y el teatro (Aurava & Meriläinen, 2022; Dorsey, 2019; López et al., 2021) – tal como se ha mostrado en el Artículo 4 de revisión sobre el *networking* STEAM-Lúdico (Rodrigues-Silva & Alsina, 2023b).

Después de explicitar lo que no es STEAM, aún en el Artículo 1, se ha definido la educación STEAM a partir de dos condiciones necesarias y suficientes. STEAM es un enfoque educativo que, en su conjunto de prácticas, promueve la enseñanza interdisciplinar de las disciplinas de Ciencias, Tecnología, Ingeniería, Artes/Humanidades y Matemáticas. Una afirmación que a primera vista parece muy obvia, pero que de ella se desprenden una serie de soluciones partiendo de lo que es más central en STEAM.

En este punto, es necesario hacer un paréntesis destacando que no se ha intentado definir la naturaleza de lo que sería un área de conocimiento STEAM. Al respecto, Ortiz-Revilla et al. (2020) proponen un modelo de discusión epistemológica en que resaltan la idea de una red sin costura (*seamless web*) de relaciones entre las áreas. En este sentido, se ha admitido que las áreas que componen STEAM se solapan creando intersecciones y, por esto mismo motivo, no se puede delimitar exactamente qué es cada disciplina. Lo que no quiere decir que las disciplinas deberían ser desconsideradas en la práctica educativa, tal como será abordado más adelante respecto a la diferencia entre interdisciplinariedad y transdisciplinariedad.

Regresando a las implicaciones de la definición de STEAM, se ha aclarado la distinción entre actividad y educación STEAM. Una actividad STEAM no necesariamente integra todas las áreas previstas en el acrónimo porque es un episodio delimitado de STEAM. La educación STEAM, sin embargo, exige la presencia de TODAS las áreas del acrónimo para ser efectivamente considerada STEAM. Esta distinción responde a la falta de consenso en la literatura sobre si STEAM debe tener todas o al menos dos disciplinas del acrónimo (Toma & García-Carmona, 2021).

Como consecuencia, se desprende que la educación STEAM debe ser alcanzada por un conjunto de prácticas que se complementan, en lugar de actividades aisladas. También se remarca que el planteamiento de actividades STEAM debe considerar las áreas de forma significativa, en lugar de completar una incorporación anecdótica. Además, esta definición explicita la inserción de áreas del conocimiento que tradicionalmente no estaban presentes en las etapas escolares: la tecnología y la ingeniería (esta consecuencia será explorada más adelante, en los Artículos 5 e 6, respecto a las concepciones del alumnado sobre la ingeniería).

En el mismo Artículo 1, se ha representado visualmente un modelo conceptual de STEAM a partir de la figura de una mesa con patas o soportes que la sostienen y objetos apoyados sobre ella. Por un lado, este modelo subraya la interdisciplinariedad y las áreas del acrónimo como los aspectos esenciales de este enfoque educativo (la superfície de la mesa). Por otro lado, el modelo establece una caracterización no exhaustiva de STEAM que permite imaginar una multiplicidad de metodologías de enseñanza y formas de aprendizaje compatibles y que dan soporte a STEAM (las patas). Además, pone de manifiesto lo que puede ser alcanzados mediante este abordaje educacional (objetos apoyados sobre la mesa): objetivos extrínsecos, del sujeto e intrínsecos de la educación.

Si en este Artículo 1 se ha destacado lo esencial de STEAM, en el Artículo 2 se hace el movimiento contrario de indagar sobre las conjeturas que no son específicas de este abordaje, pero más bien amplias de la educación y de su relación con la sociedad. Para eso, se ha visitado la teoría educacional de Gert Biesta, un reconocido filósofo da la educación que se ha destacado por un enfoque crítico a discursos y “tendencias totalitaristas” que restringen la práctica educativa (Biesta, 1998; Rømer, 2021).

En este sentido, se ha examinado lo que Biesta identifica como discurso de aprendizaje (*learnification*). Un vocabulario que, segundo él, invisibiliza el rol del docente y ofusca los objetivos educativos de cualificación, socialización y subjetivación (Biesta, 2020). Al respecto, el autor sugiere una inversión de la lógica y regreso del discurso hacia términos relacionados a la enseñanza (Biesta, 2015d). Desde el análisis de cómo estos discursos se reflejan en STEAM, se ha verificado que el discurso del aprendizaje se traduce en la idea de transdisciplinariedad.

Se ha abordado que si la transdisciplinariedad es una forma natural de entendimiento del entorno desde la movilización difusa de conocimientos; contrariamente, en la interdisciplinaridad hay enseñanza sobre la experiencia mediante la explicitación y profundización de las disciplinas y de sus intersecciones (Boufleuer & Moura, 2020). A continuación, en el Artículo 2 hemos sugerido navegar desde la transdisciplinariedad a la interdisciplinariedad, porque STEAM se diferencia como un enfoque educativo en relación a experiencias cotidianas justamente debido a la explicitación de las disciplinas y sus intersecciones, que se fortalecen a través del diálogo interdisciplinar, en lugar de estar difusas para el alumnado como acurre en la transdisciplinariedad (Boufleuer & Moura, 2020; Florentino & Rodrigues, 2015).

Por fin, el Artículo 2 interpreta la historia de la educación desde una duplicidad que la posiciona en un estado antagónico con la sociedad. Biesta (2015a) explica que, por un lado, la sociedad ha creado la escuela para cumplir el papel de formar los recién llegados, con lo cual la sociedad se ve con legitimidad de hacer demandas a la educación. Por otro lado, la escuela necesita proteger los jóvenes de las demandas de la sociedad para que estos tengan tiempo y espacio para su formación (Arendt, 1958; Martins & Rodrigues-Silva, 2022). Hemos ubicado la bifurcación entre STEM y STEAM en el centro de esta tensión, entre unos que desean un currículo enfocado en unas pocas disciplinas enfatizando su utilidad para la sociedad, y otros que apuestan por un abordaje más amplio que considere una formación más humanística del individuo.

Por fin, se resalta la educación como una práctica dotada de objetivos intrínsecos de cualificación, socialización y sujetificación pero que es demandada por la sociedad a cumplir unos objetivos extrínsecos, incluso de manera muy legítima, como lo relacionado con la urgencia de la sostenibilidad (Biesta, 2021b; Guyotte, 2020).

5.2. Entre objetivos extrínsecos e intrínsecos de la educación

En una segunda parte de la pregunta de investigación se indaga sobre cómo STEAM se relaciona con los objetivos extrínsecos e intrínsecos de la educación. Como estrategia para explorarlo, de una parte, se ha analizado la conexión de STEAM con la sostenibilidad, representando una demanda de la sociedad y, de otra parte, con lo lúdico, que no tiene compromiso inmediato con ser útil.

En este sentido, en el Artículo 3, se ha hecho una revisión sistemática de investigaciones que integran STEM o STEAM y Educación para el Desarrollo Sostenible (EDS) en educación infantil. Como resultado, ha sido posible observar que las actividades STEAM propuestas en los artículos se centran en el pilar ambiental, mientras que los aspectos sociales y económicos casi no son abordados (Rodrigues-Silva & Alsina, 2023c).

En seguida, se ha explorado la EDS en educación infantil según la orientación teórica, la perspectiva educativa y la imagen del niño. Primero, respecto a la orientación teórica, la mayoría de los autores expresan un discurso de conexión con la naturaleza, que según Somerville y Williams (2015) representa la idea de que los pequeños deben tener contacto con algún aspecto de la sostenibilidad para un crecimiento saludable y de respecto a la naturaleza. Segundo, en cuestión de perspectiva educacional, se ha observado que las prácticas pedagógicas son desarrolladas mayoritariamente desde la educación *en* la sostenibilidad, que justamente implica promover experiencias (contacto) al alumnado en algún aspecto de sostenibilidad (Davis, 2009). Además, los estudios revisados suelen concebir a los pequeños desde la figura del niño apolíneo, lo cual implica asumir que son esencialmente buenos y que se debe facilitar que emerjan atributos virtuosos en torno a la sostenibilidad desde la experiencia, como el respeto al medio ambiente (Sjögren, 2020).

Tal configuración de orientación teórica, perspectiva educativa e imagen del niño se alinea con el discurso del aprendizaje alertado por Biesta (2015). Teniendo en cuenta que los términos asociados a la enseñanza fueron evitados, los artículos revisados se enfocaron en términos como “ambiente de aprendizaje” y “facilitador del aprendizaje”. Las áreas del conocimiento STEM o STEAM no han sido explicitadas o profundizadas en la mayoría de los estudios. Con frecuencia, estas disciplinas han servido solo como categorías de análisis *a* *posteriori* en las investigaciones, identificando conocimientos movilizados de manera transdisciplinar en la experiencia. Es decir, los estudiantes mismos no identifican estas disciplinas o reconocen estos conocimientos como tal.

Desde la noción de educación como práctica teleológica (Biesta, 2022), hemos sugerido un cambio de énfasis de la "Educación para la Sostenibilidad" a la "Sostenibilidad para la Educación". A partir de esta inversión, se subraya la contribución de la sostenibilidad para la educación como proveedora de contextos para el desarrollo de enfoques educativos interdisciplinares como STEAM (Rodrigues-Silva & Alsina, 2023c).

Por otro lado, entre los documentos revisados en el Artículo 3, se destaca el estudio de Borgerding y Kaya (2018), quienes propusieron una propuesta didáctica STEAM conectando ciencias y artes para la enseñanza de características de tres biomas: desierto, ártico y bosque caducifolio. La propuesta fue metodológicamente complementada por actividades de juego, imaginación y representación de historietas, visitas al bosque y producción artística sobre los ecosistemas. En dicho estudio se aportan interesantes discusiones y reflexiones que atraviesan estas actividades y en las cuales se han incorporado explícitamente informaciones sobre estos ecosistemas, así como también consideraciones relativas al respecto ambiental.

En este sentido, se aboga por estrategias pedagógicas que apliquen el conocimiento y las habilidades STEAM para fomentar la acción-competencia. Desde este prisma, el alumnado investiga temas sostenibles (las comprenden), desarrolla visiones (imagina alternativas) y actúa para mejorar alguna situación (considera compensaciones y sacrificios individuales y colectivos y se compromete) (Jensen, 1997). Desde esta orientación, la EDS – en letras mayúsculas – se logra mediante la educación *en*, *sobre* y *para* la sostenibilidad (Davis, 2009). La acción competencia se traduce en fines intrínsecos de la educación de cualificación, socialización y, sobre todo, de subjetivación, en donde los estudiantes son llamados a reconocerse sujetos dotados de agencia, con capacidad de tomar decisiones sobre sostenibilidad y responsabilizarse por ellas (Biesta, 2020) .

Siguiendo esa misma línea, en el Artículo 8 hemos presentado una propuesta STEAM de ingeniería inversa de una mesa en la educación primaria. En un actividad de ingeniería inversa, el alumnado explora un objeto concreto en detalle, identificando sus componentes, la función de cada parte y los elementos de unión (Ladachart et al., 2022). En esta propuesta, además hicieron un plan de construcción de otras diez mesas, seleccionando materiales de un catálogo con restricciones de dimensiones, precio y preocupaciones de sostenibilidad. Para esto, el alumnado ha trabajado en grupo eligiendo roles referente a un equipo de ingeniería (socialización). Por medio de la propuesta, se han trabajado contenidos de ingeniería y matemáticas explícitamente (cualificación). Al respecto, ha sido posible evidenciar que el alumnado tuvo conciencia de la relación entre las operaciones matemáticas y sus significados físicos. Por ejemplo, sumaron unidades cuadradas para juntar partes cortadas de madera y verbalizaron que esto se traduciría en la discontinuidad de la superficie de la mesa. Como no había una única respuesta correcta, debían tomar decisiones y justificarlas (sujetificación). Este desafío ha puesto en juego habilidades de resolución de problemas, creatividad y el pensamiento crítico, de manera que la argumentación final ha movilizado competencias de sostenibilidad frente al impase entre aspectos económicos y ambientales. En suma, ha sido posible constatar que la actividad es efectiva para la enseñanza STEAM considerando la sostenibilidad al mismo tiempo de que desarrollan objetivos intrínsecos de la educación.

En este punto se hace una pausa en la discusión sobre sostenibilidad y se aborda lo lúdico como algo que no está relacionado inmediatamente a una utilidad para la sociedad (no afirmando que lo lúdico se relaciona de modo automático a objetivos intrínsecos de la educación). Al respecto, en el Artículo 4 se realiza una revisión sobre las investigaciones que integran STEAM y lúdico (Rodrigues-Silva & Alsina, 2023b). Un primer resultado ha sido observar que muy pocas investigaciones relacionan estos dos enfoques explícitamente. En este sentido, se ha observado una mirada restrictiva sobre lo lúdico que puede haber dificultado la articulación STEAM–lúdico. Algunos investigadores y profesores conciben lo lúdico únicamente como actividades fruto de la acción voluntaria, autogestionada por los niños y con el fines en ellas mismas (Rodrigues-Silva & Alsina, 2022a; Zosh et al., 2018).

Diferentemente, Zosh et al. (2018) abogan por una conceptualización de lo lúdico como un espectro que contempla actividades más o menos estructuradas y coherentes con objetivos educativos. Desde este marco más amplio, se han constatado experiencias enmarcadas en STEAM que han sido desarrolladas a partir de metodologías de enseñanza del enfoque lúdico, como el juego libre, el juego guiado, el juego formal y la gamificación (Rodrigues-Silva & Alsina, 2023b). Se ha observado en STEAM y lo lúdico la manifestación y desarrollo de la creatividad (pensamiento divergente), o bien la satisfacción por el reto y por la búsqueda de soluciones a problemas con restricciones y límites (Bondi & Bondi, 2021;

Mineiro & D'Ávila, 2019), una conjetura particularmente similar a problemas de ingeniería (Moore et al., 2014).

A partir de la revisión de estas experiencias, se ha evidenciado el éxito de STEAM-lúdico en todos los niveles educativos y edades. En el Artículo 9, hemos presentado una propuesta STEAM de expresión dramática sobre la ingeniería. Estudiantes de ingeniería mecánica participaron en laboratorios de preparación de autores, planificaron, escribieron y presentaron una obra de teatro sobre su curso. En esta actividad, se ha verificado la movilización de conocimientos de ingeniería, matemáticas, ciencias y artes, en específico el lenguaje del teatro (cualificación). En la obra, se identifican diversos episodios dónde se alcanzan objetivos educativos intrínsecos. Por ejemplo, han representado un personaje que interrumpe un culto a las máquinas y han advertido sobre el papel de la comunidad ingeniera en trabajar para el bienestar humano (socialización). De repente, los estudiantes se liberan de la ilusión tecnológica despojándose de una cubierta robótica y asumiendo su humanidad. Este acto evidenció que la actividad teatral expresa un llamamiento de los estudiantes a reconocerse como sujetos que tienen responsabilidades por encima de las máquinas (sujetificación).

A partir de lo discutido, se puede conjeturar que tanto en un planteamiento que involucra la sostenibilidad como en lo lúdico, suele haber un problema o desafío que configura un contexto en el cual naturalmente se pueden movilizar conocimientos de diversas disciplinas. Sin embargo, se hace hincapié que para desarrollar las actividades STEAM es necesario partir de un planteamiento con intenciones claras para su ejecución, explicitando y profundizando conocimientos asociados a estas disciplinas, así como también relacionados al objetivo extrínseco como de sostenibilidad (Borgerding & Kaya, 2018).

5.3. Implicación sobre la enseñanza y la formación docente

En este subapartado, se centran los esfuerzos en responder a una tercera parte de la pregunta de investigación respecto a cuáles son las implicaciones de la educación STEAM para la enseñanza y la formación docente. De antemano, se resalta que una definición concisa de la educación STEAM hace ver que promover este enfoque educativo significa: a) el desarrollo de todas las áreas del acrónimo y no únicamente algunas de ellas, b) la enseñanza interdisciplinar de al menos dos de las áreas del acrónimo en cada actividad, y c) la coordinación de las prácticas educativas para que, en su conjunto, promuevan ecuánimemente todas las áreas del acrónimo. Desde estos tres puntos centrales de STEAM se despliegan una serie de implicaciones para la enseñanza y para el profesorado.

La integración de todas las áreas del acrónimo STEAM incide directamente en la incorporación de áreas que no estaban tradicionalmente presentes en el currículo escolar, como la ingeniería y tecnología (Moore et al., 2014). En este sentido, en Estados Unidos se ha introducido la ingeniería como un proceso de diseño asociado a la disciplina de ciencias, específicamente relacionado al proceso investigativo (NGSS, 2013). España ha explicitado la competencia STEM en su currículo de educación primaria, en ella fomenta "*la tecnología y los métodos de la ingeniería para transformar el entorno de forma comprometida, responsable y sostenible*" (MEFP, 2022). Sin embargo, es necesario indicar más claramente los contenidos y habilidades involucrados y como se relacionan con los ya preexistentes.

Al respecto, Moore et al. (2014) proponen un modelo de enseñanza de la ingeniería preuniversitaria estableciendo una serie de criterios de calidad y criticando la reducción de la ingeniería al diseño. Estos autores consideran como calidad en la enseñanza de la ingeniería, por ejemplo, el criterio *Problemas, Soluciones e Impactos* que aproxima la actividad ingenieril a la sostenibilidad. Definen también el criterio *Ética*, que trata sobre decisiones del sujeto e introducción a la cultura y las prácticas de la comunidad de ingeniería. Además, estos autores aportan el criterio *Concepciones sobre ingeniaría y la persona ingeniera,* que se refiere al desarrollo de ideas más precisas sobre esta área del conocimiento y solventando estereotipos.

Respecto a la importancia del abordaje explícito de las áreas del conocimiento, en el Artículo 5 se ha realizado una revisión sistemática de estudios que exploran las concepciones que el alumnado tiene sobre la ingeniería y sobre la persona ingeniera. Se ha evidenciado que el alumnado de países como Estados Unidos (Capobianco et al., 2011), China (Chou & Chen, 2017) y Turquía (Ata-Aktürk & Demircan, 2021), desde edades muy tempranas, mayoritariamente concibe a la persona ingeniera como varón que actúa individualmente en actividades manuales y desde ambientes externos. Seguidamente, tal como se ha presentado en el Artículo 6, se han explorado las concepciones que 18 estudiantes españoles de educación primaria tienen sobre la ingeniería usando el instrumento "Dibuje una persona que hace ingeniería" (DAET, por su acrónimo en inglés). Se ha observado que los participantes exhiben ideas erróneas sobre esta profesión y área del conocimiento. Aproximadamente el 80% del alumnado representa la ingeniería desde actividades equivocadas o estereotipadas (manuales). El 70% identifica el uso de las matemáticas en la ingeniería de manera simplista o descontextualizada y dos tercios de ellos no hacen referencia alguna a la aplicación de las ciencias en la ingeniería.

La literatura ha indicado que las concepciones estereotipadas sobre la ingeniería pueden empeorar con el tiempo si no son combatidas, a ejemplo del sesgo de género que es más prominente en estudiantes de más edad (Capobianco et al., 2011), así como también desde planteamientos didácticos mal formulados (Fleer, 2021; Matusovich et al., 2021). Como estrategia, Silva-Hormazábal et al. (2022) han propuesto una actividad STEAM en la cual estudiantes de educación primaria analizaron sus propias respuestas al DAET y reflexionaron sobre sus concepciones en torno a la ingeniería.

En este sentido, tanto la revisión como el estudio empírico realizado en España refuerzan la necesidad de trabajarse explícitamente la ingeniería y, de manera cautelosa, evitar y combatir estereotipos. Con ello, se pone de manifiesto que los docentes necesitan una formación en la que desarrollen sus propias concepciones y les permitan hacer planteamientos adecuados de actividades de ingeniería en la escuela (Vo & Hammack, 2022).

Durante la formación docente reportada en el Artículo 7, se ha sugerido al profesorado planificar actividades STEAM explicitando las disciplinas y el método de enseñanza utilizado. Respecto al método de enseñanza, han señalado que su identificación ha sido uno de los retos de la tarea, con lo cual, sintieron la necesidad de investigar y profundizar sobre ellos para considerarlos de manera efectiva en el planteamiento STEAM. El análisis de las planificaciones STEAM ha evidenciado que logran aplicar explícitamente métodos de enseñanza, especialmente el Aprendizaje Basado en Proyectos (ABP) y aprendizaje Basado en la Investigación (ABI). En este sentido, cabe destacar que más del 70% del profesorado ha utilizado métodos de enseñanza que eran nuevos para ellos. Es destacable que, al final, reportaron que la variedad de métodos de enseñanza es una ventaja de STEAM.

Se pueden destacar ventajas de una conceptualización de STEAM compatible con una multiplicidad de metodologías de enseñanza. Por un lado, se evita configurar STEAM como una expresión abanico que toma el lugar de términos ya consolidados en la literatura (Toma & García-Carmona, 2021). Por otro lado, se evidencia la necesidad de beneficiarse de las experiencias y los conocimientos históricamente construidos sobre estas metodologías de enseñanza (Rodrigues-Silva & Alsina, 2022b).

Aun refiriéndose a la formación reportada en el Artículo 7, se ha instruido al profesorado a explicitar las disciplinas trabajadas en las planificaciones STEAM, así como también identificando los conocimientos y habilidades movilizados y destacando los elementos de intersección entre ellas. Además, se les ha enfatizado que la incorporación de las áreas debería ser significativa, en lugar de forzar disciplinas desde una presencia anecdótica. Como resultado, ellos reportaron que hacer efectiva la interdisciplinariedad entre las áreas STEAM ha sido el reto más grande del planteamiento. Sin embargo, se ha superado esta dificultad, por lo que todos participantes han logrado integrar al menos dos disciplinas, y la mitad integraron las cinco áreas STEAM. Conjuntamente, cabe destacar que el profesorado ha indicado que fueron incentivados a aprender sobre las demás áreas de conocimiento STEAM. Adicionalmente, han señalado que la interdisciplinariedad es una ventaja de este enfoque educativo.

Finalmente, una vez analizados los artículos de revisiones (Artículos 3 y 4) e implementaciones de STEAM (Artículos 8 y 9) relacionados con la sostenibilidad y lo lúdico, ha sido posible enfatizar que en las dos situaciones existe la oportunidad de alcanzarse objetivos intrínsecos de la educación. Esta constatación concilia los objetivos extrínsecos e intrínsecos de la educación en diferentes ocasiones. En este sentido, se resalta que los objetivos intrínsecos de la educación no deben quedarse en segundo plano. Respecto a la sostenibilidad, se ha defendido la inversión de “educación para la sostenibilidad” a “sostenibilidad para la educación” (Rodrigues-Silva & Alsina, 2023c). Respecto a lo lúdico, se ha abordado desde una conceptualización de lo lúdico no restrictiva que incorpora su potencial educativo (Zosh et al., 2018).

En este punto, cabe abrir un paréntesis para subrayar que las múltiples y frecuentemente incoherentes demandas de la sociedad generan una sensación de disfuncionalidad en la educación (Biesta, 2019). Sin embargo, la educación no estaría en perfecta armonía incluso si se centrara en objetivos intrínsecos. En este sentido, la educación enfrenta problemas como la falta de recursos, una alta carga de trabajo y una formación insuficiente del profesorado (Rodrigues-Silva, 2020). Es cierto que la muestra del estudio 7 configura un grupo de profesores inicialmente predispuestos a la capacitación, mientras que la implementación de STEAM encuentra resistencia por parte de algunos profesores.

De este modo, se resalta la agencia y la motivación del propio profesorado. Una conclusión importante ha sido que las actividades específicas STEAM deben ser coordinadas para alcanzar el objetivo amplio de este enfoque educativo. En este sentido, por un lado, la interdisciplinariedad se hace desde el diálogo entre disciplinas (Danermark, 2019); por otro lado, los profesores y otros actores involucrados también necesitan dialogar.

Rowe (2008, p. 6) menciona cinco factores de éxito de la investigación interdisciplinar. Hemos adaptado este factores a la enseñanza interdisciplinar y añadimos un sexto factor que se refiere al pensamiento reflexivo (Engelbertink et al., 2020). De este modo, se enumeran seis factores de éxito para el maestro STEAM:

1. Apertura genuina a las perspectivas y actitudes de los docentes de otras disciplinas;
2. Respeto mutuo entre los docentes del equipo;
3. Habilidades y conocimientos complementarios entre los docentes;
4. La capacidad de los docentes para desarrollar un lenguaje común;
5. La capacidad de los docentes para reunirse regularmente;
6. La capacidad de los docentes para reflexionar sobre la práctica docente.

En este sentido, el diálogo requiere del profesorado estar abierto e interesado en lo que el otro tiene que decir. Requiere humildad para que todos perciban que necesitan de los demás, donde una disciplina no se imponga a la otra como una perspectiva oficial y total. De esta manera, el acceso al conocimiento de los demás es una forma constructiva de revalorización de los propios supuestos, lo que conduce a una aprehensión profunda y crítica del campo disciplinar (Boufleuer & Moura, 2020).

Se hace necesaria una formación docente que impulse la práctica y la teoría educativa de forma simbiótica, de modo que el profesorado sienta la necesidad y perciba la ventaja de indagar sobre la actividad docente y apoyándola con la teoría (Rodrigues-Silva & Alsina, 2021). Solo así es posible preparar a los docentes para el desafío de promover la interdisciplinariedad en las áreas STEAM, al tiempo que incorpora metodologías de enseñanza consideradas efectivas en términos de aprendizaje activo, colaborativo, auténtico, significativo y lúdico para los estudiantes (Michael, 2006; Zosh et al., 2018).

Será imprescindible proponer planes de formación apoyados en la reflexión para empoderar la subjetivación del profesorado, quien debe construir una agencia docente que le permita tomar decisiones acerca de los temas relevantes para la sociedad, como la sostenibilidad, pero sin olvidar los objetivos intrínsecos de la educación (Biesta, 2022).

5.4. Limitaciones y perspectivas futuras

En primer lugar, en esta tesis doctoral, el análisis STEAM inserido en la educación se ha fundamentado principalmente en la filosofía educacional de Gert Biesta. Si bien esto puede ser una virtud, ya que ha permitido profundizar en el concepto desde una perspectiva concreta, puede haber sido también una limitación, asumiendo que el diálogo y la reflexión con otras corrientes de pensamiento pueden fortalecer la caracterización de STEAM desde otros referentes filosóficos. Por lo cual, será necesario seguir explorando el locus de STEAM en la educación considerando diferentes prismas de la filosofía de la educación.

En segundo lugar, se ha revisado la conexión entre STEM/STEAM y la sostenibilidad en la educación infantil, de modo que el análisis queda limitado en relación al alumnado de esta etapa educativa. Por consiguiente, será necesario expandir esta exploración usando las categorías de orientación teórica, de perspectiva educativa e incluso de imagen del niño para analizar los estudios realizados en etapas posteriores.

En tercer lugar, se ha explicitado que las áreas del conocimiento están relacionadas entre ellas como en una red sin costura (Ortiz-Revilla et al., 2020). De modo que las definiciones de ciencia, tecnología, ingeniería, artes/humanidades y matemáticas se superponen y están en permanentemente negociación y reconstrucción. Asimismo, se ha valorado que las disciplinas son particiones comprensibles del conocimiento que permiten su organización y comprensión (Florentino & Rodrigues, 2015). En este sentido, es una limitación de esta investigación que no se haya profundizado en unos rasgos principales de cada disciplina para orientar el profesorado. Hasta el momento, se han destacado únicamente particularidades de la ingeniería, pero en el futuro sería necesario desarrollar también las demás disciplinas. La experimentación empírica estuvo limitada durante el periodo de doctorado a causa de la pandemia de la Covid-19. Como estrategia, se ha profundizado en la exploración teórica en torno a STEAM. Sin embargo, será relevante avanzar y ampliar muestras en investigaciones que sitúen el panorama de la ingeniería temprana en la escuela, además de ofrecer propuestas didácticas con las cuales el profesorado y el alumnado visualice las conexiones de la ingeniería con las matemáticas y las ciencias y con otras áreas STEAM, así como también se trabaje una idea no estereotipada de la ingeniería.

En síntesis, esta tesis doctoral abre nuevos caminos para plantear e investigar más propuestas STEAM donde se conjeturen los objetivos intrínsecos de la educación: cualificación, cualificación y subjetivación. Desde este marco, en el futuro será interesante ampliar la formación docente centrada en la idea concisa de STEAM, de modo que incorpore reflexión no solo sobre el planteamiento, sino también sobre la implementación de actividades STEAM. Adicionalmente, deberá explorarse la modalidad de Enseñanza a Distancia y formatos como *Massive Open Online Course* (MOOC) que posibilitan llegar a un número elevado de maestros, en formación y en activo.

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ANNEX

Following, we present published articles or proceedings developed within the doctoral context but were not incorporated into the thesis's main body.

Article A. Formação docente no modelo realista-reflexivo: uma aproximação do contexto brasileiro

Digital Object Identifier (DOI) link: https://doi.org/10.21680/1981-1802.2021v59n60ID24757

Journal: Revista Educação em Questão (ISSN 1981-1802)

Publisher: Federal University of Rio Grande do Norte

Country: Brazil

Indexed in: Latindex, Periodicos da CAPES, IRESIE, DIALNET, DOAJ, REDIB

Metrics: Latindex. Catalogue v1 (2002 - 2017): 34 accomplished characteristics; Qualis CAPES (triennium 2017–2020) = A1.

Article B. Brazilian and Spanish mathematics teachers' predispositions towards gamification in STEAM education

Digital Object Identifier (DOI) link: http://dx.doi.org/10.3390/educsci11100618

Journal: Education Sciences (ISSN 2227-7102)

Publisher: Multidisciplinary Digital Publishing Institute (MDPI)

Country: Switzerland

Indexed in: Emerging Sources Citation Index, Scopus, DOAJ, EBSCO Education Source, Educational research abstracts (ERA), ERIC (Education Resources Information Center), Psycinfo

Metrics: Emerging Sources Citation Index (ESCI): JCI = 1.21 (1st quartile); Scimago Journal & Country Rank (SJR) = 0.61 (2nd quartile); Qualis CAPES (triennium 2017–2020) = A2

Article C. Teachers' predispositions toward playful learning: Implications for teacher training

Digital Object Identifier (DOI) link: https://doi.org/10.21680/1981-1802.2021v59n60ID24757

Journal: Revista Educacao & Formacao (ISSN 2448-3583)

Publisher: Federal University of Ceará

Country: Brazil

Indexed in: Emerging Sources Citation Index (ESCI), Latindex, Periodicos da CAPES, DIALNET, DOAJ, Educational research abstracts (ERA), MLA - Modern Language Association Database

Metrics: Emerging Sources Citation Index (ESCI): JCI = 0.39 (3rd quartile); Latindex Catalogue v2: 35 accomplished characteristics; Qualis CAPES (triennium 2017–2020) = A3.

Article D (proceeding paper). Mathematics embedded in STEAM approach in primary education: a systematic literature review

Event: Simposio en Investigación en Educación Matemática (ISSN 2952-0045)

Publisher: Sociedad Española de Investigación en Educación Matemática

A

ARTICLE A

Formação docente no modelo realista-reflexivo

Uma aproximação do contexto brasileiro

Rodrigues-Silva, J., & Alsina, Á. (2021). Formação docente no modelo realista-reflexivo: Uma aproximação do contexto brasileiro. *Revista Educação Em Questão*, *59*(60), 1–28. https://doi.org/10.21680/1981-1802.2021v59n60id24757

Artigo
DOI | 10.21680/1981-1802.2021v59n60ID24757

Formação docente no modelo realista-reflexivo: uma aproximação do contexto brasileiro

Jefferson Rodrigues-Silva
Instituto Federal de Minas Gerais (Brasil)
Ángel Alsina
Universidade de Girona (Espanhal)

Resumo

O modelo de formação docente realista-reflexivo consiste em uma abordagem neovygotskiana de construção colaborativa dos conhecimentos descritivo e normativo em simbiose com a prática por meio da reflexão crítica cíclica e autorregulada: consideram-se as experiências e os conhecimentos prévios, o sistema de crenças e os valores dos professores. Este artigo tem o objetivo de aproximar esse modelo ao contexto brasileiro, apresentando suas principais características, etapas, ciclos reflexivos, marcas de autorregulação, guia da aprendizagem e rubrica de avaliação. Observa-se a pertinência do modelo para o país e sua potencialidade, e também precauções, para sua adoção na Educação a Distância (EaD). Conclui-se que o Brasil pode ser beneficiado com a formação de professores no prisma realista-reflexivo, sobretudo na modalidade de EaD. Esse ainda é um campo pertinente que precisa ser intensamente pesquisado e praticado.
Palavras-chave: Formação realista-reflexiva. Formação docente. Educação a distância.

Teacher formation within the realistic-reflective model: an approach to the Brazilian context

Abstract

The realistic-reflective teacher formation model consists in a neo-Vygotskian collaborative construction approach of descriptive and normative knowledge in symbiosis with practice through self-regulated cyclical critical reflection: it considers teachers' prior experiences and knowledge, the system of beliefs and values. This article aims to bring this model closer to the Brazilian context, presenting its main characteristics, stages, reflective cycles, self-regulation marks, and guide for learning evaluation rubric. It is observed the relevance of the model for the country and its potential, and also its precautions, for Distance Education (EaD) adoption. We conclude that Brazil can benefit from teacher formation in the realist-reflective perspective, especially in the EaD modality. This is still a pertinent field that needs to be intensively researched and practiced.
Keywords: Realistic-reflective formation. Teacher formation. Distance Education.

La formación docente en el modelo realista-reflexivo: una aproximación al contexto brasileño

Resumen

El modelo de formación docente realista-reflexivo consiste en un enfoque neo-vygotskiano de construcción colaborativa de los conocimientos descriptivo y normativo en simbiosis con la práctica, a través de la reflexión crítica cíclica y autorregulada: se consideran las experiencias de los docentes y sus conocimientos previos, el sistema de creencias y los valores del profesorado. Este artículo tiene como objetivo acercar este modelo al contexto brasileño, presentando sus principales características, etapas, ciclos reflexivos, marcas de autorregulación, guía del aprendizaje y rúbrica de evaluación. Se observa la relevancia del modelo para el país y su potencialidad, y también las precauciones, para su adopción en la Educación a Distancia (EaD). Se concluye que Brasil puede beneficiarse de la formación docente en la perspectiva realista-reflexiva, especialmente en la modalidad EaD. Este todavía es un campo relevante que necesita ser intensamente investigado y practicado.

Palabras clave: Formación realista-reflexiva. Formación docente. Educación a distancia.

Introdução

O paradoxo socrático *"ipse se nihil scire id unum sciat"* traduzido do latim como "só sei que nada sei" (ADKIN, 1999) é um ponto de partida importante para a filosofia da educação. Observando homens que se achavam sabedores, Sócrates observa que sabe mais que eles: pelo fato de dar-se conta de que ele não sabe. A frase conjuga-se em um paradoxo porque Sócrates sabe pelo menos uma coisa, que ele não sabe! (DAMO, 2015).

Isso implica que sempre se sabe algo, mas nem sempre se tem consciência do desconhecido (DAMO, 2015). Kruger e Dunning (1999, p. 30) chegaram empiricamente à essa conclusão. Eles constataram que "[...] as habilidades que geram competência em um determinado domínio são, muitas vezes, as mesmas habilidades necessárias para avaliar a competência nesse domínio". Dessa forma, ocorre um fenômeno que ficou conhecido como efeito Dunning-Kruger: aqueles que menos sabem, por serem incapazes de avaliarem o (des)conhecimento, são confiantes e sobrevalorizam suas habilidades; já aqueles que mais sabem, por vislumbrarem a complexidade do tema, tendem a ser cautelosos e, por vezes, inseguros.

A ideia da transmissão passiva de conhecimentos povoa a ficção literária: como na obra de Stoker (2020), onde Drácula aprende a língua inglesa bebendo sangue de um inglês. Ou ainda, a transmissão de conhecimentos normativos e o controle social por meio de fármacos como a droga SOMA da distopia Admirável Mundo Novo de Hurxley (2014).

Entretanto, alunos de uma formação pedagógica (inicial ou continuada), por exemplo, não são recipientes vazios aptos a serem passivamente preenchidos com conhecimentos e teorias (ALSINA; MULÀ, 2019). Podemos argumentar sobre isso apresentando dois motivos: de um lado, eles não estão vazios, pois existirão conhecimentos implícitos, crenças e experiências prévias (ESTEVE; MELIEF; ALSINA, 2010); de outro lado, eles podem não estar aptos por não saberem que não sabem e, portanto, não estarem convencidos da necessidade da própria formação. Além disso, como Korthagen (2010, p. 98) critica a transmissão passiva de conhecimentos (entendido aqui como métodos tradicionais de aula expositiva) dizendo que se desejamos alunos com "[...] capacidade de construir seu próprio conhecimento, de refletir sobre suas próprias visões de mundo e de desenvolver sua identidade pessoal e missão na vida". Devemos pensar a formação dos professores em coerência a isso.

O modelo realista-reflexivo possui essa coerência partindo dos conhecimentos e experiências prévios, e sistema de crenças para a transformação profissional. Fomentando o desenvolvimento de uma identidade profissional adequada: por meio da reflexão individual e social, de forma autorregulada e autônoma: capacidade de decidir (ESTEVE; ALSINA, 2020), com a incorporação teórica mediante a significação dos conceitos (ALSINA; MULÀ, 2019). 3

Ele apresenta-se como uma terceira via à dicotomia entre o "[...] aprender a teoria antes para aplicá-la depois [...] ou o [...] aprender na prática (estágio, tentativa e erro)" (ESTEVE; MELIEF; ALSINA, 2010). Onde aprendizado ocorre de maneira simbiótica entre a prática e a teoria (ALSINA; BATLLORI; FALGÁS; GÜELL; VIDAL, 2016). A formação é planejada e executada com instrumentos e atividades que possibilitem e fomentem ciclos de reflexão completos, como no modelo ALACT (sigla melhor explicada adiante no texto - Action, Looking back on the action, *Awareness of essential aspects, Creating alternative methods of action, Trial)* (ESTEVE; MELIEF; ALSINA, 2010). Autonomia do professor na autorregulação do aprendizado e por meio de rubricas de avaliação específicas, como a Rubrica de Avaliação da Reflexão Narrativa (NARRA) (ALSINA; AYLLÓN; COLOMER, 2018).

O modelo já é uma realidade em países como Espanha e Países Baixos (ALSINA; BATLLORI, 2013; ESTEVE; MELIEF; ALSINA, 2010). Este artigo tem o objetivo de aproximar esse modelo ao contexto brasileiro, apresentando-se suas principais características, etapas, ciclos reflexivos, marcas de autorregulação, e rubrica de guia e verificação da aprendizagem. Observa-se a pertinência do modelo para o país e sua potencialidade e precauções para a Educação a Distância (EaD), um novo campo que se abre a novas investigações.

1. Formação realista-reflexiva

1.1. Por que uma formação realista-reflexiva?

Assim, consideramos a existência de duas matemáticas. Essas diferentes mateÉ senso comum que a prática docente não pode apoiar-se na mera intuição, no empirismo e na tentativa e erro (ESTEVE; MELIEF; ALSINA, 2010). Faz-se necessária a incorporação de conhecimentos chaves e lições a serem aprendidos de uma base científica de diversas áreas ligadas à formação de professores (ALSINA; MULÀ, 2019). Por outro lado, os cursos tradicionais apresentam uma teoria na forma descritiva que nem sempre é bem compreendida ou percebida como pertinente para o professor em formação. Este, muitas vezes, frustra-se ao tentar colocá-la em prática, percebendo que o conhecimento não se traduziu em competências e habilidades, por fim, o professor passa a enxergar a teoria como desnecessária, incorreta ou desconexa com a sua realidade (BOGHOSSIAM, 2006).

Korthagen (2010) propõe um modelo de cebola para os níveis de reflexão do docente com uma visão holística de aspectos profissionais e pessoais, incluindo contexto (físico-social), comportamento, competências, crenças, identidade e missão; desde o nível mais superficial ao mais profundo respectivamente.

Benedict XVII (2007, p. 24, tradução nossa) diferencia dois tipos de conhecimentos: cumulativo e não cumulativo. No primeiro caso é possível um progresso incremental, como na ciência, por exemplo, em que ele vai aumentando. "No entanto, no campo da consciência ética e da tomada de decisões morais, não há possibilidade semelhante de acumulação pela simples razão de que a liberdade do homem é sempre nova e ele deve sempre tomar suas decisões de novo".

Sidorkin (2018, p. 1227) explica que o conhecimento cumulativo é descritivo, enquanto o não cumulativo é normativo. Segundo ele, "[...] [a]

prática da educação não é homogênea a esse respeito: em algumas áreas, simplesmente damos às pessoas um conhecimento descritivo sem um objetivo normativo claro". O conhecimento descritivo não atua diretamente no comportamento, educadores inclinam-se em direção à normatividade. Porém, o autor adverte sobre um paradoxo da cumulatividade e seus efeitos inesperados: conhecimentos normativos são do tipo: "você deve fazer isso" ou "você não deve fazer aquilo", esse conhecimento "[...] aciona a cláusula de livre arbítrio e sua aceitação torna-se uma questão de escolha" (p. 1228). Dessa forma, conhecimento se tornam crenças, que são fortes em nos mover, mas fracas porque podemos não aceitá-las.

Assim, a adoção de um quadro normativo e a imposição de uma conduta e de um perfil indenitário profissional "padrão" poderá não atingir os efeitos almejados. Sendo pertinente, apresentar diversas formas diferentes de trabalhar e pensar a agencia docente: autonomia e a capacidade de saber decidir (ESTEVE; ALSINA, 2020).

Entendo a relação holística, complexa e sistêmica existente elementos explicitados Korthagen (2010) no modelo de cebola. Propomos um modelo, não hierárquico (em termo de profundidade), mas que se faça a distinção entre aspectos internos: conhecimento teórico (descritivo e normativo), competências, crenças, valores e domínio afetivo; de aspectos externamente visíveis: contexto, recursos (humanos, materiais e tecnológicos), comportamento e discurso. No centro e na interface entre o interno e o externamente visível, encontram-se a identidade profissional e pessoal e a missão do sujeito. O modelo é nomeado como campo de futebol, por seu formato como pode ser visto na Figura 1.

Figura 1
Modelo de campo de Futebol sobre a identidade pessoal e profissional e sua missão do professor.

6 Por meio dele podemos observar que a externalização no comportamento do professor de um conhecimento teórico aprendido e de competências desenvolvidas é um processo complexo e que engloba mais elementos complementares e por vezes condicionantes, como o contexto e os recursos disponíveis.

Assim, o professor pode ter um determinado conhecimento teórico e as competências necessárias para aplicá-lo, mas observa-se que por efeito de algum elemento, ou mais provavelmente alguns outros combinados, ele estabelece outro discurso ou tem comportamento incoerente. Ele pode não acreditar nesse conhecimento; ter conflito com seus valores éticos, morais ou religiosos; ou achar incompatível com seu estado no domínio afetivo (pode estar desmotivado, por exemplo, e sabe que tal prática lhe exigiria maior esforço). Ou ainda, o contexto em que o docente se encontra, a exemplo a pandemia da Covid-19 ou a falta de recursos restringe a possibilidade de diversas atividades.

Hanna, Oostdam, Severiens e Zijlstra (2019, p. 22) fizeram uma revisão bibliográfica de instrumentos quantitativos sobre a identidade profissional, na qual foram capazes de "[...] categorizar seis domínios – autoimagem, motivação, compromisso, autoeficácia, percepção da tarefa e satisfação no trabalho – que podem ser vistos como demarcações importantes e relevantes da identidade do professor". No modelo de futebol a Identidade profissional é posicionada ao meio indicando que ela interage com todos os elementos internos e externamente visíveis, e que, portanto, para atuar na construção dessa identidade a formação e as experiências vividas pelo professor devem abranger esses elementos.

Faz-se preciso uma formação realista-reflexiva que escape das dicotomias entre "aprender a teoria para aplicar depois" ou "aprender na prática" (ESTEVE; MELIEF; ALSINA, 2010), entre "conhecimento descritivo" e "conhecimento normativo" (SIDORKIN, 2018) e que incorpore fatores mais amplos da prática docente como a capacidade de decidir (ESTEVE; ALSINA, 2020) e a identidade profissional docente (HANNA; OOSTDAM; SEVERIENS; ZIJLSTRA, 2019). Esteve, Melief e Alsina (2010) propõem uma terceira via: o modelo realista-reflexivo. Este se caracteriza por aprender da prática simbioticamente com a teoria, considerando os conhecimentos e experiências prévias, diversas forma de atuar e o contexto físico-social em que o professor se insere (ALSINA, 2019).

"Como a maioria das boas ideias, entretanto, suas raízes são bem mais antigas" (SHULMAN, 1986, p. 4). Alsina (2019) explica que o modelo realista-reflexivo que converge três principais pressupostos: teoria sociocultural (VYGOTSKY, 1978), a reflexividade do profissional docente (SCHÖN, 1983) e uma perspectiva realista do ensino (FREUDENTHAL, 1991). A seguir se aprofunda o estudo do modelo realista-reflexivo. 7

1.2. O modelo realista-reflexivo

Para observar as principais características do modelo, começamos explorando as três etapas de desconstrução, co-construção e reconstrução de uma formação realista-reflexiva dentro de um processo de transformação de conhecimentos, crenças e valores à competência profissional (identidade profissional) (ESTEVE; MELIEF; ALSINA, 2010). Depois, apresenta-se o ciclo reflexivo ALACT (KORTHAGEN, 2010) relacionando-o com essas etapas. Então, se conhecerão as 12 marcas de autorregulação de Alsina, Batllori, Falgás e Vidal (2019) e a Rubrica de Avaliação da Reflexão Narrativa (NARRA) (ALSINA; AYLLÓN; COLOMER; FERNANDEZ-PEÑA; FULLANA; PALLISERA; PÉREZ-BURRIEL; SERRA, 2017).

Alsina, Batllori, Falgás e Vidal (2019) identificam três etapas na formação realista-reflexiva: 1) desconstrução: estudantes tomam consciência das experiências prévias, dos conhecimentos implícitos, dos valores e crenças, ocorre o conflito cognitivo; 2) co-construção: interação com a metodologia da formação (contexto universitário), com a teoria, e social (entre pares e o professor formador) de compartilhamento dos conhecimentos implícitos, valores e crenças, que suportam a reflexão e a construção de conhecimento; finalmente 3) reconstrução: envolve interação consigo e com a prática (contexto da escola), nessa etapa evidencia-se a transformação dos conhecimentos implícitos, valores e crenças em conhecimento crítico e competência profissional. Entre as etapas, observam-se os quatro tipos de interações distinguidos desde uma perspectiva socioconstrutivista por Van Lier (2004): consigo, com iguais, com especialistas e com conceitos.

Da teoria vygostkiana, pode-se destacar o processo social, esta cria uma dinâmica de aprendizagem interativa: primeiro internamente, o professor sente a necessidade de reflexão e da estruturação do pensamento para conseguir expressar um discurso sobre o seu conhecimento, suas experiências, valores e crenças (ALSINA; BUSQUESTS; ESTEVE; TORRA, 2006). Em seguida, ele observa diferentes interpretações sobre a prática e o saber docente e compara fazendo novas reflexões (ALSINA; BATLLORI; FALGÁS; GÜELL; VIDAL, 2016).

A Figura 2 ilustra o referido processo de transformação, destaca-se na parte superior (verde) a trajetória do professor em formação. Partindo dos conhecimentos prévios e sistema de crenças, passando pelas três etapas descritas anteriormente de Desconstrução, co-construção e reconstrução.

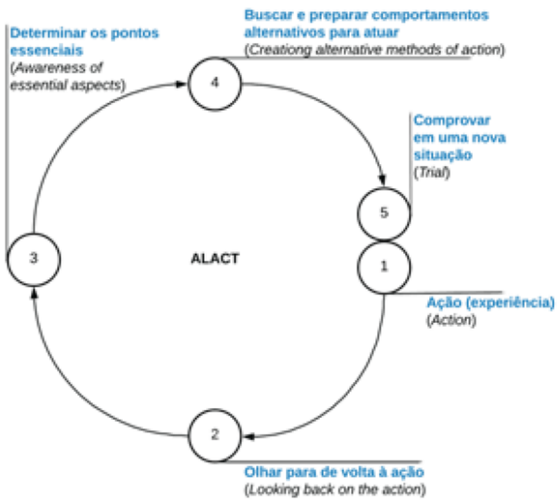
Figura 2
Elementos para a transformação profissional docente (ALSINA; MULÀ, 2019, tradução nossa).

Conflitos cognitivos e contradições, destacado na etapa de desconstrução, ocorrem porque o professor reflete sobre comportamentos que ele desenvolveu por hábito, e não tinha refletido sobre eles. Porque ele percebe uma variedade de formas de atuação. Conforme mencionado anteriormente no modelo de campo de futebol na Figura 1, pode haver incoerência entre elementos internos e externamente visíveis, por exemplo, entre o discurso e o comportamento sobre um determinado tema; a tomada de consciência dessa incoerência também gera conflito cognitivo.

Ainda tratando sobre a mesma imagem, na parte inferior apresentam-se ações e atividades da formação (professor em formação). Estas se relacionam com os processos de transformação dos alunos, e por isso devem estar sincronizadas (SERDÀ; ALSINA, 2013). Propõem-se desafios, manejam-se os conflitos cognitivos e a incorporação de teoria, conduz-se o processo reflexivo.

O modelo circular do ciclo reflexivo permite atravessar etapas de desconstrução, co-construção e reconstrução do conhecimento (ALSINA; BATLLORI; FALGÁS; GÜELL; VIDAL, 2016). O modelo ALACT se baseia na alternância entre "ação" e "reflexão" (ALSINA; BATLLORI; 2013). Como pode ser visto na Figura 3.

Figura 3
Modelo ALACT: Sigla do inglês - ação, olhando de volta para a ação, consciência de aspectos essenciais, criando métodos alternativos de ação, comprovar em uma nova ação



Observam-se no modelo ALACT cinco fases, ação ou experiência; olhar para trás de volta à ação; determinar os pontos essenciais; buscar e preparar comportamentos alternativos para atuar; e comprovar em uma nova situação (ALSINA; BATLLORI; FALGÁS; GÜELL; VIDAL, 2016). O ciclo permite que os próprios alunos, individual e socialmente, e de maneira autônoma e autorregulada (ESTEVE; MELIEF; ALSINA, 2010) construam o seu conhecimento normativo, a partir do desenvolvimento da capacidade de decidir (ESTEVE; ALSINA, 2020), na observação de diversas formas de agir, e a busca por conhecimento teórico (descritivo), segundo uma necessidade percebida.

1.3. Portfólio

O portfólio é um instrumento de guia que possibilita a autorregulação da aprendizagem pelo aluno (ALSINA; BATLLORI, 2013), fomentando um diálogo interno importante para a percepção da evolução (via comparação do ponto de partida e o estado atual), além de ser um espaço para observar o ciclo ALACT: com reflexão sobre a prática, sobre a aprendizagem e sobre as próprias reflexões, chamada metarreflexão (SERDÀ; ALSINA, 2013; ALSINA;BATLLORI, 2013).

Serdà e Alsina (2013) aplicaram a ferramenta portfólio continuamente à formação realista-reflexiva e, por retroalimentação dos alunos, progressivamente foram evoluindo-a. Os resultados apontaram para a necessidade de orientação para as atividades do portfólio, incluindo competências, objetivos, avaliação e bibliografia. Sugeriu-se também que os conteúdos das aulas e as atividades do portfólio estejam coordenados, por exemplo, utilizando-se um cronograma. Os resultados do trabalho direcionaram, ainda, para o uso de plataformas digitais (como o Moodle) com um portfólio misto (papel e digital), com avaliações e retroalimentações automáticas, e tutoria para suporte dos alunos, permitindo uma aprendizagem adaptável e sincronizada ao ritmo dos alunos.

A seguir são tratadas as marcas de autorregulação que são identificadas na formação realista-reflexiva com o uso de portfólio (ALSINA; BATLLORI; FALGÁS; VIDAL, 2019) e depois se aborda a Rubrica de Avaliação da Reflexão Narrativa (NARRA) que podem ser designadas com a função de avaliação progresso dos alunos (ALSINA; AYLLÓN; COLOMER; FERNANDEZ-PEÑA; FULLANA; PALLISERA; PÉREZ-BURRIEL; SERRA, 2017) e também como guia e instrumento de autorregulação (ALSINA; AYLLÓN; COLOMER, 2018).

1.4. Marcas de autorregulação

Alsina, Batllori, Falgás e Vidal (2019, p. 57) pesquisaram o conjunto de marcas de autorregulação: elementos do processo formativo que devem ser tratados de forma explicita pois permitem "[...] assumir metas, planejar sua atuação, observá-la com uma visão crítica e avaliar as próprias estratégias para formular novas ações de melhoria". Os autores identificaram cinco marcas presentes principalmente na etapa de desconstrução: experiências prévias; crenças sobre si mesmo; crenças sobre o funcionamento da aula; conhecimento disciplinar implícito (conteúdo) e conhecimento didático implícito (pedagógico). Ainda mais sete marcas que se concentrariam nos momentos de co-construção e desconstrução: interação com o contexto do centro escolar; interação com contexto da universidade; interação subjetiva; interação com os pares; interação com o especialista; interação com a teoria e conhecimento profissional crítico.

As marcas de autorregulação são importantes para que o aprendizado não se restrinja à carga horária do curso, mas que ela ocorra ao longo de toda vida profissional (ALSINA; BATLLORI; FALGÁS; VIDAL, 2019). A seguir observa-se uma breve descrição de cada uma das doze marcas de autorregulação aplicado à formação de professores na matemática. Aqui se propõe pensar essas marcas de uma forma abrangente a outras áreas do conhecimento:

> 1. Experiências prévias: situações passadas que deixaram a sua marca na construção da identidade matemática ou na construção da identidade profissional para o ensino da matemática.
> 2. Crenças sobre si mesmo: o olhar interno como aluno ou como futuro professor.
> 3. Crenças sobre o funcionamento da aula: os preconceitos sobre as linhas metodológicas das escolas, a forma de gerir a prática docente de cada professor e ainda as relações entre os profissionais.
> 4. Conhecimento disciplinar implícito: a visão sobre a matemática e os conhecimentos que a compõem.
> 5. Conhecimento didático implícito: visão sobre como ensinar matemática.
> 6. Interação com o contexto do centro escolar: o contraste com o contexto da sala de aula escolar a partir da observação participante e da aprendizagem situada.

> 7. Interação com o contexto da universidade: o contraste com o contexto da sala de aula universitária baseado na participação ativa e na aprendizagem situada.
> 8. Interação subjetiva: diálogo introspectivo.
> 9. Interação com os pares: comunicação com os outros.
> 10. Interação com o especialista: comunicação com o formador.
> 11. Interação com a teoria: o contraste com a teoria (disciplinar e didática) vinculado à construção da identidade profissional.
> 12. Conhecimento profissional crítico: o resultado do processo de construção autorregulada da própria identidade profissional, que inclui competências profissionais e o pensamento crítico (ALSINA, 2019, p. ANO 69-70).

As marcas de autorregulação respondem aos principais aspectos da formação realista-reflexiva, como uma abordagem que considera as experiências prévias, crenças e conhecimentos implícitos dos professores junto com a interação com a teoria (ESTEVE; MELIEF; ALSINA, 2010). Além disso, observam-se elementos relacionados à realidade da prática docente e os contextos que ele transita, escola e universidade; e o sua interação social, consigo mesmo, pares e especialistas. As marcas de autorregulação veem-se refletidas em instrumentos de avaliação da aprendizagem, como a Rubrica de Avaliação da Reflexão Narrativa (NARRA), que é tratada a seguir.

1.5. Rubrica de Avaliação da Reflexão Narrativa (NARRA)

Alsina, Ayllón e Colomer (2018) explicam que a Rubrica de Avaliação da Reflexão Narrativa (NARRA) foi proposta e validada na perspectiva dual: avaliativa e guia na aprendizagem, ela se configura como uma estrutura em que se expressam as marcas de autorregulação, onde "deve haver uma internalização, de um nível de funcionamento inter-psicológico para um nível intrapsicológico, para que ele possa se tornar uma ferramenta de aprendizagem que aciona uma avaliação formativa autorregulada" (ALSINA; AYLLÓN; COLOMER; FERNANDEZ-PEÑA; FULLANA; PALLISERA; PÉREZ-BURRIEL; SERRA, 2017, p. 151).

Alsina, Batllori, Falgás, Güell e Vidal (2016) estabeleceram quatro elementos da rubrica: a) Situação, atividade ou experiência que desencadeia a reflexão; b) preconcepções e crenças; c) investigação e foco; d) transformação. Estes elementos possuem indicadores que são avaliados em níveis de 1 a

4, segundo critérios específicos a cada elemento, como pode ser observado na Tabela 1. Fernández-Peña, Saurina, Serra, Fullana, Alsina, Colomer, Ayllón, Burriell e Pallisera 2016 propõem o instrumento validado para ser aplicado sobre narrativas reflexivas feitas por alunos na etapa de reconstrução da formação realista-reflexiva de modo a se verificar de modo estrutura as marcas de autorregulação e a completude do ciclo ALACT de Korthagen, Kesseils, Koster, Lagerwerf e Wubbels (2001).

Tabela 1
Rubrica de Avaliação da Reflexão Narrativa

Indicadores	*Níveis da rubrica*			
	1	*2*	*3*	*4*
ELEMENTO 1: Situação, atividade ou experiência que desencadeia a reflexão. Seleção e análise de uma situação sobre a qual será feito o processo reflexivo.				
1.1. Identifica e descreve o foco da reflexão de uma forma contextualizada.	Não identifica fontes de reflexão sobre uma experiência específica.	Identifica focos de reflexão de uma experiência concreta e vivida, mas é trivial ou pouco importante.	Identifica um foco significativo de reflexão sobre uma experiência específica e vivida.	Identifica um ou mais focos relevantes de reflexão sobre uma experiência concreta e vivida.
1.2. Faz julgamentos sobre o foco da reflexão.	Escreve uma dissertação retórica e descontextualizada.	Escreve uma descrição fora do contexto.	Escreve uma descrição que carece de alguns elementos de contexto.	Escreve uma descrição contextualizada.

Tabela 1
Rubrica de Avaliação da Reflexão Narrativa (continuação)

Indicadores	*Níveis da rubrica*			
	1	*2*	*3*	*4*
ELEMENTO 2: Preconcepções e crenças: consciência das próprias crenças, dos conhecimentos e das experiências prévios..				
2.1 . Especifica, analisa e elabora crenças ou ideias sobre si mesmo.	Não especifica ideias ou crenças prévias sobre si mesmo.	Especifica algumas ideias ou crenças prévias sobre si mesmo, sem aprofundamento na explicação	Especifica ideias ou crenças prévias sobre si mesmo e as analisa.	Especifica ideias ou crenças prévias sobre si mesmo, as analisa e avalia. Por exemplo, explica porque chegou nessas crenças e as relaciona com experiências pessoais e analisa sua história.
2.2 . Especifica, analisa e elabora sobre ideias ou crenças prévias sobre o contexto	Não especifica ideias ou crenças prévias sobre o contexto.	Especifica ideias ou crenças prévias sobre o contexto sem explicá-las.	Especifica ideias ou crenças prévias sobre o contexto e as analisa.	Especifica ideias ou crenças prévias sobre o contexto e as analisa e avalia.

Tabela 1
Rubrica de Avaliação da Reflexão Narrativa (continuação)

2.3 . Especifica, analisa e elabora sobre ideias ou crenças sobre a disciplina / profissão.	Não especifica ideias ou crenças prévias sobre a profissão ou disciplina.	Especifica ideias ou crenças prévias sobre a disciplina ou profissão sem explicá-las.	Especifica ideias ou crenças prévias sobre a disciplina ou profissão e as analisa.	Especifica ideias ou crenças prévias sobre a disciplina ou profissão e as analisa e avalia.
ELEMENTO 3: Indagando e / ou focalizando: pesquisando possíveis ações dos alunos por meio de focalização, perguntas e hipóteses.				
3.1. Foca sobre problemáticas e hipóteses e faz perguntas sobre o foco de reflexão.	Não especifica problemáticas ou hipóteses sobre o foco de reflexão.	Especifica problemáticas ou hipóteses gerais sobre si mesmo, mas não as examina ou discute.	Especifica e se concentra em problemáticas e hipóteses sobre foco de reflexão, mas não as expande. O aluno não desenvolve um processo de investigação sobre o foco ou reflexão.	Especifica e se concentra em problemáticas e hipóteses e também inicia um processo de investigação sobre o foco de reflexão.

Tabela 1
Rubrica de Avaliação da Reflexão Narrativa (continuação)

Indicadores	*Níveis da rubrica*			
	1	*2*	*3*	*4*
3.2. Foca sobre problemáticas e hipóteses e faz perguntas sobre o contexto.	Não especifica problemáticas ou hipóteses sobre o contexto..	Especifica problemáticas ou hipóteses gerais sobre o contexto, mas não as examina ou discute..	Especifica e se concentra em problemáticas e hipóteses sobre o contexto, mas não as expande. O aluno não desenvolve um processo de investigação em contexto.	Especifica e se concentra em problemáticas e hipóteses que podem levar a um processo de investigação no contexto.
3.3. Foca sobre problemáticas e hipóteses sobre a ação profissional.	Não especifica problemáticas ou hipóteses sobre a atuação profissional.	Especifica problemáticas ou hipóteses sobre a profissão ou disciplina científica, mas não as examina ou discute.	Especifica e se concentra em problemáticas e hipóteses sobre a atuação profissional, mas não as expande. O aluno não desenvolve um processo de investigação sobre a ação profissional.	Especifica e se concentra em problemáticas e hipóteses que podem levar a um processo de investigação sobre a profissão ou disciplina.

Tabela 1
Rubrica de Avaliação da Reflexão Narrativa (continuação)

ELEMENTO 4: Transformação: Definindo objetivos de aprendizagem concretos e futuros planos de ação, aproximando-se a um novo ciclo de reflexão. Mudança de paradigma. Argumentação sobre mudanças ou a sua necessidade.				
4.1 Especifica, defende e transfere novas metas de aprendizagem.	Não especifica novos objetivos de aprendizagem para a transformação de qualquer crença, experiência ou conhecimento prévio (sobre si mesmo, sobre o contexto ou a profissão).	Especifica objetivos de aprendizagem para a transformação de algumas crenças, experiências e / ou conhecimentos prévios (sobre si mesmo, sobre o contexto ou a profissão), mas não os discute.	Não especifica novos objetivos de aprendizagem para a transformação de qualquer crença, experiência ou conhecimento prévio (sobre si mesmo, sobre o contexto ou a profissão).	Especifica objetivos de aprendizagem para a transformação de algumas crenças, experiências e / ou conhecimentos prévios (sobre si mesmo, sobre o contexto ou profissão), mas não os discute.
Indicadores	*Níveis da rubrica*			
	1	*2*	*3*	*4*
4.2. Programa novos planos de ação, e os apoia com argumentos.	Não programa ações de melhoria.	Programa ações de melhoria, mas não os discute.	Programa ações de melhoria, mas as discute com deficiências e / ou erros.	Programa ações de melhoria e as argumentasem deficiências e erros, fechando o ciclo reflexivo.

Fonte: (ALSINA; AYLLÓN; COLOMER; FERNANDEZ-PEÑA; FULLANA; PALLISERA; PÉREZ-BURRIEL; SERRA, 2017, tradução nossa).

Engelbertink, Colomer, Woudt- Mittendorff, Alsina, Kelders, Ayllón, Westerhof (2020) usaram a rubrica NARRA em um estudo empírico realizado com alunos de diferentes cursos de graduação dos Países Baixos. Eles puderam concluir que refletir sobre emoções pode ser chave em atingir a reflexão crítica. E, ainda, que distinguir os componentes identificados por Hanna, Oostdam, Severiens e Zijlstra (2019) na Identidade profissional (autoimagem, motivação, compromisso, autoeficácia, percepção da tarefa e satisfação no trabalho) fornece uma imagem mais refinada sobre a habilidade de reflexão dos estudantes.

Alguns obstáculos

Morin (1990) explora extensamente os malefícios do reducionismo de sistemas complexos. Referenciando novamente o modelo de campo de futebol apresentado na Figura 1, quando apenas um ou alguns elementos são tomados como causas para determinado comportamento do professor, observa-se a tendência à culpabilização em vez de um entendimento integrado e que se retroalimenta. Poderíamos destacar duas frequentes reduções.

Uma primeira redução é atribuir unicamente ao professor toda a responsabilidade pelo seu comportamento, desconsiderando a sua formação, o contexto em que ele está inserido e os recursos que lhes são oferecidos. Nesse caso ele sente um grande peso sobre si, culpando-se e frustrando-se por não conseguir atuar em coerência com a sua identidade pessoal, profissional e/ou missão. Ele sentirá que a sua formação não responde à sua realidade, e, além disso, perigosamente pode-se fomentar uma visão de que o professor precisa sacrificar-se a qualquer custo para atingir sua função, um objetivo a pesar de entraves que lhes são extrínsecos: com apoio material e social ausente ou insuficiente.

Uma segunda redução é a isenção da potência e da responsabilidade individual e culpabilização das condições extrínsecas: os alunos, a direção da escola, o sistema escolar, a falta de recursos o governo, etc. Nessa interpretação o professor pode ser tratado, e/ou sentir-se, como uma vítima. Desqualificando qualquer tentativa de formação que lhe é oferecida, uma vez que o seu comportamento estaria limitado unicamente a condições externas, o que geralmente não é o caso.

Alsina, Batllori, Falgás, Güell e Vidal (2016) citam alguns possíveis obstáculos na implantação desse tipo de formação. Existe a necessidade de se mudar a forma de ensinar, de aprender e de avaliar: uma tarefa desafiadora que nem toda universidade, ou outro centro de formação de professores, mostrar-se-ão dispostos a enfrentar. Requer-se a reflexão sobre a prática, consciência de conhecimentos prévios e crenças. Tudo isso emerge do contraste de ideias com o outro e com a teoria e pode provocar conflito emocional.

O manejo adequado desse conflito para culminar na transformação das preconcepções em competência profissional exigirá um arcabouço de novas ferramentas (portfólios, textos narrativos, questionários, etc.) que podem oferecer dificuldades tanto ao desenvolvimento dos estudantes quanto aos professores responsáveis no processo de avaliação (ALSINA, MULÀ, 2019). E se não for bem administrado podem atuar como barreiras à aquisição de novos conhecimentos e exercerem uma influência negativa sobre a construção da própria identidade profissional (ALSINA; BATLLORI; FALGÁS; GÜELL; VIDAL, 2016).

Alguns alunos expressam incômodos para falar em público e compartir crenças, relatam dificuldade na realização de tarefas de forma autônoma, como a pesquisa teórica (ALSINA, 2019). Alguns sugerem que o uso contínuo de ferramentas que promovem diálogos reflexivos poderia causar uma sensação de monotonia (ALSINA, MULÀ, 2019).

Os obstáculos, como estes aqui apresentados, não são impedimentos para implantações do modelo no Brasil, ou em outros lugares. Estratégias adequadas e os devidos cuidados devem ser tomados. Faz-se necessário um contínuo desenvolvimento teórico do modelo e de suas ferramentas, tal como pesquisas empíricas a fim de aprimorá-lo.

Formação realista-reflexiva na Educação a Distância (EaD)

Alsina (2019) relata experiência em curso de formação realista-reflexiva para alunos de licenciatura em matemática da Universidade (Desidentificada para avaliação por pares), na Espanha. Com via formativa dupla, modalidade presencial e outra híbrida (semipresencial) com guias de aprendizagem: apostando nessa opção para aqueles alunos que não poderiam assistir às aulas presenciais ou como solução para aqueles que se sentiam incomodados com o modelo na modalidade presencial ou apresentavam dificuldade de falar em público.

Em particular no contexto da pandemia da Covid-19, Esteve e Alsina (2020) fazem recomendações para o planejamento e gestão de atividades que promovam o desenvolvimento da identidade profissional docente na Educação a Distância. Faz-se servir fóruns de discussão com perguntas de sistematização do conhecimento e da reflexão individual e coletiva, no formato escrito ou no upload de vídeos à plataforma digital, e ainda espaços para retroalimentação. Para a efetivação desse aprendizado, os autores tratam sobre "[t]rês questões inter-relacionadas: fomentar a agência docente, projetar atividades que representem um desafio cognitivo para o aluno e direcionem a tomada de decisões com fundamentação (atividades prolépticas) e a mediação conceitual e social pelo formador especialista" (p. 03, tradução nossa).

Esteve e Alsina (2020, p. 10, tradução nossa) argumentam por uma estrutura com "[...] diretrizes específicas relacionadas a cada etapa do roteiro de trabalho [...]" (desafio cognitivo) e que funcione como um "[...] andaime construtivo planejado anteriormente e que permita incorporar ajudas pontuais segundo as necessidades que surjam ao longo de toda a atividade" (p. 8, tradução nossa). Dessa forma, Esteve e Alsina (2020) abordam como a mediação do professor formador se incorpora nessa estrutura.

> [O]s apoios fornecidos pelo especialista, sejam eles quais forem, podem ser prestados online, através de aplicações como Google Meet, Microsoft Teams, Zoom ou Blackboard Collaborate, entre outros: cápsulas formativas baseadas em gravações curtas onde o conhecimento teórico é fornecido, apresentações em PowerPoint ou outros formatos semelhantes, artigos teóricos, etc (ESTEVE; ALSINA, 2020, p. 11).

Relatos de experiências do modelo realista-reflexiva em estruturas híbridas e apontamentos para cursos na modalidade de ensino de Educação a Distância, tudo isso, nos direcionam à possibilidade da formação realista-reflexiva nessa modalidade. Resguardados os cuidados que se deve tomar para não perder de vista os objetivos do modelo realista-reflexivo, há relevância impar pensar esse modelo na modalidade de Educação a Distância para um país com dimensões continentais como o Brasil.

Formação Realista-reflexiva no Brasil

No Brasil, existe o curso intitulado *Formação realista-reflexiva baseada na obra "A arte de ser um perfeito mau professor"*, este é oferecido pelo (Instituição suprimida para avaliação por pares) (RODRIGUES-SILVA, 2020) e é o primeiro e único curso encontrado que explicitamente se caracteriza dentro do paradigma em pesquisa no Google. Há alguns poucos cursos com abordagens similares, por exemplo, a Formação "em ação" dos cursos de Pedagogia a distância da Universidade Federal do Rio Grande do Sul (UFRGS) e da Universidade Federal de Pelotas (UFPEL) (ARAGÓN; ZORZI; TURCHIELO, 2020).

Relembrando o objetivo desse estudo, propõe-se aproximar o modelo realista-reflexivo ao contexto brasileiro. Uma indagação importante a se fazer é sobre a sua pertinência aos membros da Comunidade de Países de Língua portuguesa (CPLP), dentre eles o Brasil (CPLP, 2020). É evidente que a formação docente deve estar alinhada com a realidade e cultura do país em que esse professor atuará.

O modelo realista-reflexivo, reforçando, advoga centralmente sobre a relação íntima e simultânea entre prática e a teoria. Nele se considera o ponto de partida do professor quanto às suas experiências e os conhecimentos prévios, crenças e valores (ESTEVE; MELIEF; ALSINA, 2010). O desenvolvimento das capacidades e da identidade profissional se dá por ciclos reflexivos com fases de pensamento individual e construção coletiva, de forma que o contexto social local interfere no processo de aprendizagem (ENGELBERTINK; COLOMER; WOUDT- MITTENDORFF; ALSINA; KELDERS; AYLLÓN; WESTERHOF, 2020).

Tratando agora especificamente sobre o Brasil que é numericamente muito expressivo em função do seu tamanho geográfico e populacional. O Instituto Nacional de Estudos e Pesquisas Educacionais Anísio Teixeira (Inep) contabilizou 176.403 docentes na rede pública e 209.670 na rede privada, totalizando mais de 386 mil professores em exercício na educação superior do país em 2019 (BRASIL, 2019). Já para a educação básica, o Inep registrou em 2020 uma quantidade de 2,2 milhões de docentes, sendo que a maior parte deles (63,0%) atua no ensino fundamental (BRASIL, 2021a). Sobre a qualificação dos docentes que atuam nos anos iniciais é interessante observar que nem todos possuem uma formação pedagógica: 81,8% possuem grau superior de licenciatura, porém 3,5% têm formação de bacharelado, 10,0%

têm ensino médio normal/magistério, ainda 4,7% com nível médio ou inferior (BRASIL, 2021a).

O Conselho Nacional de Educação (CNE), quem define as diretrizes curriculares nacionais gerais para a educação profissional e tecnológica, versou sobre a formação docente, exigindo formação pedagógica (ou comprovação desse conhecimento) dos professores bacharéis para atuar nesse nível, incluindo aqueles que já estão em exercício e que ingressaram quando não havia essa exigência, conforme ratificado em resolução emitida em 2021 (BRASIL, 2021b).

Sobre os cursos de licenciatura, observa-se crescimento da EaD, que já supera a modalidade presencial. No ano de 2019 as matrículas em cursos de licenciatura presencial representam 46,7%, enquanto EaD são 53,3% no total de matrículas" (BRASIL, 2019, p. 22).

Finalmente, relacionando o panorama brasileiro, é pertinente pensar uma formação realista-reflexiva inicial, mas também continuada, pois a qualificação dos professores que atuam no Ensino Básico e as novas exigências para o docente do ensino tecnológico indicam que nem todos os professores em exercício têm formação pedagógica adequada para estarem atuando. No país observa-se o crescimento da modalidade EaD, de forma que a formação realista-reflexiva deve ter em vista a atuação do professor nessa modalidade, como em cursos massivos abertos (AMADO, 2020). Além disso, é interessante observar a própria formação realista reflexiva na modalidade EaD, já que a maioria dos cursos de licenciatura já são EaD, e ainda, associado às dimensões continentais e ao alto número de professores, futuros e em exercício.

Considerações finais

Na ficção cientifica o conhecimento pode ser transmitido de forma passiva, como Drácula o recebe pelo sangue (STOKER, 2020) ou a população recebendo conhecimento normativo por fármacos (HUXLEY, 2014). Conforme abordado nessa pesquisa, numa formação no modelo realista-reflexivo, porém, os conhecimentos descritivos e normativos, as competências e a identidade profissional, nada disso pode ser transmitido ou transferido já com significados impregnados, mas precisa ser construído pelo próprio indivíduo (ALSINA; BATLLORI; FALGÁS; GÜELL; VIDAL, 2016) exercendo a sua autonomia e autorregulação do aprendizado e, assim, desenvolvendo sua capacidade de decidir (ESTEVE; ALSINA, 2020).

Dessa forma, como o modelo realista-reflexivo parte da realidade e das preconcepções do professor e os objetivos de aprendizagem são personalizados, dependem e atuam sobre essa mesma realidade, pode-se concluir que o modelo se mostra adequado ao contexto Brasileiro, pois versará sobre essa realidade. Nesse caso, somado ao grande número de professores e ao tamanho continental do país, faz-se pertinente estudar as possibilidades do modelo realista-reflexivo na modalidade de Educação a Distância, na formação inicial e continuada, resguardados os cuidados metodológicos que garantem o desenvolvimento da Identidade profissional docente, conforme já apontado na literatura.

Por fim, ressalta-se que o contexto brasileiro abre um campo de crescimento e pesquisa do modelo realista reflexivo, requerem-se estudos empíricos, avanços em transpor limitações identificadas e futuras, com a análise de ferramentas e estratégias que possibilitem melhorá-lo, por exemplo, a validação/tradução de rubricas como o NARRA ao português.

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Prof. Ms. Jefferson Rodrigues-Silva

Instituto Federal de Minas Gerais (Brasil)

Departamento de Engenharia Mecânica

Grupo de Pesquisa Grup de Recerca en Educació Científica i Ambiental (GRECA)

Orcid id: https://orcid.org/0000-0002-8334-2107

E-mail: jefferson.silva@ifmg.edu.br

Prof. Dr. Ángel Alsina
Universidade de Girona (Espanha)
Departamento de Didáticas Específicas
Grupo de pesquisa Grup de Recerca en Educació Científica i Ambiental (GRECA)
Orcid id: https://orcid.org/0000-0001-8506-1838
E-mail: angel.alsina@udg.edu

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ARTICLE B

Brazilian and Spanish mathematics teachers' predispositions towards gamification in STEAM education

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education sciences

Article

Brazilian and Spanish Mathematics Teachers' Predispositions towards Gamification in STEAM Education

Paula López [1,*], Jefferson Rodrigues-Silva [1,2] and Ángel Alsina [1]

[1] Department of Specific Didactics, University of Girona, 17080 Girona, Spain; jeffe.rodri@gmail.com (J.R.-S.); angel.alsina@udg.edu (Á.A.)
[2] Department of Mechanical Engineering, Federal Institute of Minas Gerais, Belo Horizonte 30000-000, MG, Brazil
* Correspondence: paula.lopez@udg.edu; Tel.: +34-972-418-332

Abstract: This article reports a multiple case study in which we analyse Brazilian and Spanish mathematics teachers' opinions about and predispositions toward gamified activities in STEAM education. To obtain data, we administered a survey to 56 in-service mathematics teachers in primary and secondary education from these countries. The survey had been previously validated throughout an expert judgement process. Our results show a high percentage of teachers who think this kind of activity has positive effects on students' development, improving their affective domain toward mathematics and required skills for mathematical competency. Notwithstanding, many teachers report insecurity and lack of training for employing such educational methodologies.

Keywords: teacher predispositions; gamification in education; gamifying learning; STEAM education; mathematics; Brazil; Spain

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1. Introduction

Fostering students' motivation, engagement, and behavioural changes is an appealing objective that researchers argue the gamification of education could achieve [1–4]. Additionally, it seems desirable to educate people with interdisciplinary knowledge and develop skills and abilities for autonomously and critically acting, living, and working in a complex and ever-changing twenty-first-century world, which is promised by STEAM Education—an interdisciplinary approach among the areas of Science, Technology, Engineering, Arts and Humanities, and Mathematics [5]. Therefore, we could conjoin these goals by thinking of gamification as an educational strategy for pursuing and promoting STEAM Education [6], for example, in mathematics [7].

STEAM Education has recently become a trend in educational development [8] that promotes learning throughout and for the interdisciplinary enterprise [5]. We find it across all educational stages: from early childhood education until higher education [4,9]. Originally, the term STEAM derived from the acronym STEM [10]. The National Science Foundation (NSF) in the 1990s formalised the acronym STEM concerning the four areas of Science, Technology, Engineering, and Mathematics [11]. Afterward, STEAM Education emerged as a new pedagogy during the Americans for the Arts-National Policy Roundtable discussion in 2007 "to help counterbalance the increased focus on STEM subjects and the decline in arts education in the U.S." [10] (p. 32).

STEAM has cognitive and affective objectives, namely STEAM Literacy [12], and also democratic and utilitarian goals (skill development) [13]. STEAM is based on educational philosophies such as Deweyan pragmatism and the premise that learning should be constructed through (reflection about) experience [14]. The term STEAM aligns well with many methods [5] especially active and collaborative ones, e.g., the maker movement, Project Based Learning (PjBL), Problem Based Learning (PBL) [8], augmented reality [15], and gamification [6].

Gamification is a neologism derived from the digital media field [16]. The first use of this concept, in 2003, is attributed to Nick Pelling, a British game developer. [1]. Although gamification is a relatively young topic, it is an increasing research interest topic [2,3]. A bibliometric survey showed the geographic distribution of research in the gamification of education: from 100 countries, the United States of America has the largest share of publications on the subject (almost 13%), while Spain comes closely behind with almost 9%; the results placed Brazil in the fifth position in the list (4.2%) [4].

Deterding et al. [17] (p. 02) define gamification as "the use of game design elements in a non-game environment". Although there is no consensus of a specific definition and scope for gamification, according to the literature review, the definition from Deterding et al. [17] is the most widespread and accepted [1,18]. Among these game elements, we encounter reward-action contingency (RACs): leader boards, scoring, and badges [19]. Additionally, mission, narrative, character, level, aim, resources and items, and collaboration are game elements applied in learning gamification [18]. However, if we have applied game elements, how does gamification work in a non-game environment? One major difference between gamification and designing conventional games remains because we apply gamification regarding some desired outcomes from a particular context, while also providing some enjoyment. The latter has internal objectives concerning pure entertainment [18].

Mora et al. [18] found in a literature review of 40 publications generic framework designs for gamification (35%) and frameworks for specific contexts, which they categorised as business (45%), learning (15%), and health (5%). Hamari et al. [2] found empirical studies of gamification in various contexts. In this paper, we address studies of gamification in the educational context.

In education, gamification is reported as a powerful tool for teachers at all levels in the educational system [1]. Hamari et al. [2] reviewed the literature in empirical studies of gamification and observed that educational context was the most reported. All articles reviewed reported learning outcomes as mostly positive: increasing motivation, engagement, and enjoyment. Additionally, gamification encourages extracurricular and interdisciplinary learning [1]. Mora et al. [18] acknowledged a consensus that design frameworks in education explicitly reveal the importance of defining clear objectives. Gamification differs conceptually from serious games in this aspect. Serious games immerse learners into the gameplay and attempt to hide educational objectives. In gamification, educational objectives are visible [1]. According to the literature, researchers commonly report unclear objectives as the main reason for failure in gamification designs [18].

The literature suggests gamification as an active method for STEAM education. Cleophas [6], for example, reported a case study of STEAM-gamified activity employed in Brazil. She designed and applied it using many game elements, such as score, a classification table, and progress feedback. She included content knowledge of the history and fundamentals of chemistry: chemical bonds, formulas, stoichiometric balance, reactions, and ammonia synthesis. She pointed to interdisciplinarity within STEAM areas: including poetry and caricature (Arts) and chemical calculations and logic association (Mathematics). The author considered that the activity also involved technology and engineering, although she treated them as resources and not proper knowledge areas. Technology was referred to as the use of technological tools, mobile applications and social media, and engineering simply as applying manipulative material for constructing molecules. Cleophas [6] argued that the STEAM gamified approach permitted graduating challenges, promoting spaces for feedback, motivating and engaging students, and fostering collaboration among them.

Mendes et al. [20] reviewed gamification applied to teaching deaf students and related to learning sign language. They note that this usage was reported in few countries, e.g., Brazil, Egypt, and Romania. According to them, gamification is in its commencement as an inclusive strategy, but it has already been shown as an avenue for creating communication systems between deaf people and deaf people and listeners through sign language.

In mathematics education, as an area that is part of STEAM education, gamification is present from the first educational levels [21,22] and throughout all the stages, especially in secondary education [23]. Computer science, social sciences, engineering, and mathematics are, in this order, the most reported areas in the gamification of education [4]. However, gamification in mathematics is sometimes misconceived, and the term gamification is improperly used in the description's framework and/or the analysis of games. Muñoz et al. [24] points to four key characteristics that should be met in a gamified activity in mathematics: (1) it proposes a problem to be individually or collaboratively solved to achieve rewarded objectives; (2) it creates challenges between users; (3) it accounts for scores, so that students receive gifts or prizes; and (4) it creates levels and rankings so that students can receive feedback, compete, and compare their results. These indicators maintain strong links with an approach to teaching mathematics through mathematical processes of problem-solving, reasoning and proof, communication, connections, and representation, more linked to thinking and doing than to memorising concepts and reproducing procedures [25].

Based on a review of gamified activities in mathematics, we find several digital games where students have to perform tests to achieve a goal using technological devices, e.g., mobile phones [26–28]. Jagušt et al. [1] (p. 451), for example, reported an empirical study about a gamified lesson using tablets in lower primary mathematics classes in competitive, adaptive, and collaborative conditions. Compared to the control group, non-gamified activity, "three other gamified conditions showed positive trends in terms of several solved tasks as time passed, with the adaptive condition being the most prominent, followed by competitive and collaborative conditions". Notwithstanding, the adaptive condition was statistically significant as causing the greatest amount of stress among students and led to the greatest number of incorrect task competition attempts. The authors also re-examined error role in education, arguing that gamification may provide a welcoming ambience for incorrect answers in the initial phases, and this strategy can be effective for learning.

Despite the excitement around gamification, there is some controversy. Mora et al. [18] observed that some frameworks consider using technology as a prerequisite for gamification, while some researchers support that "[g]amification can also be done completely offline by adding motivational narratives as a prequel to an activity or by awarding paper badges or medals for certain educational achievements" [1] (p. 456). In this sense, gamification could be associated with object-based learning (OBL) [29], wherein manipulative materials play a pedagogical role. Most frameworks of gamification address fun as a relevant aspect to be considered during the design process of gamification. Issues such as risk, feasibility, and investment are often disregarded [18]. It is worth remarking that Dubbels [19] argues that gamification is reported as easy or expensive to construct, compared to game design.

Hamari et al. [2] pointed out that some studies showed that the results of gamification may not be long term, but caused by a novelty effect. A decrease in students' motivation and satisfaction over time has been reported, comparing gamified with non-gamified courses [1]. Muñoz et al. [24] warned that repetition of this type of activity ends up causing boredom in students, whom we intend to motivate a priori. Disengaged students are powerfully motivated when facing something new, but as soon as they have to apply the knowledge they still do not have, and if they do not promptly learn with these activities, these students end up disconnecting quickly. Others reported possible negative outcomes that need to be paid attention to, such as increasing competition, task evaluation difficulties, and design features. It seems that gamification alone may not sustain the effects on students' interest, motivation, and satisfaction levels [1].

Studies and experiences with escape rooms have also proliferated [30–32], which again present the same problem: it creates great expectations when used for the first time, but since we cannot repeat it, once its features become known, it loses the initial potential for motivation. This type of activity also has the disadvantage of requiring much work to be prepared, and then it is hard to be adapted to other students or other contents. This does not happen when using games in mathematics class, as it has been implemented for decades.

The existing literature addresses true gamification in learning mathematics, while some experiences misconceive gamification in mathematics by referring to it when concerning game usage in education. Additionally, the previously commented upon inconsistencies and controversies found around the subject should be considered. Altogether, this also leads to a requirement for investigation into teachers' opinions, since they are indeed agents with a relevant role in teaching. Studies have analysed teachers' beliefs about gamification, and they have found that teachers have positive opinions about it [33–35]. For example, students develop learning, skills, and the affective domain [33,34] in a gamified teacher training course [35]. Notwithstanding, there are practically no studies in Spain and Brazil that have analysed the effect of implementing gamification as a tool to promote mathematics learning and instruction. Concerning gamification, Alabbasi [34] concluded that teachers have a positive perception of incorporating it into online learning. They consider, for example, that gamification improves students' motivation towards course goals, elevates students' satisfaction, and promotes the urge to go beyond the requirements of the course. It increases attention and the curiosity to navigate multiple elements in the learning management system [34].

STEAM Education research also lacks an understanding of teachers' beliefs [36–38]. Kim and Bolger [36] remark that despite Korean teachers considering that STEAM educational programs can have a positive impact on elementary education, many are reluctant to take part in STEAM education. Teachers' negative perception of STEAM education is mainly justified by their belief in insufficient training and experience [36]. Teachers may have different perceptions of interdisciplinary approaches, e.g., secondary teachers who exhibit a more negative view of the potential impact of STEM education on student achievement when compared to primary teachers [38]. Among the concerns, teachers report an increase in their workload, difficulty in coordinating with teachers from other knowledge areas [38], and a lack of support from peers and school administration [37].

Considering the background described and these gaps in the literature, this study aims to analyse the predisposition of mathematics teachers in primary and secondary education to carry out gamification activities in STEAM education.

2. Materials and Methods

This is a multiple case study [39], employed as descriptive research with a mixed design: a quantitative and a qualitative part, which are interrelated in the way that one complements the other.

2.1. Participants

Participants of the study are 56 mathematics teachers, 24 being in-service in Brazil and 32 in Spain. They work with students whose average age ranges from 10 to 16 years old. Table 1 summarises sample distribution by gender and education level for both countries.

Table 1. Research sample of Spanish and Brazilian teachers was distributed per gender and education level.

Gender/Education Level [1]	Spain		Brazil	
	Primary School (10–12 Years)	Secondary School (12–16 Years)	Primary School (10–14 Years)	Secondary School (14–16 Years)
Woman	8	13	7	8
Man	4	7	2	7
Total	12	20	9	15

[1] Original education level names of primary school and secondary school in Spain, Educación Primaria and Educación Secundaria, and in Brazil, Ensino Fundamental and Ensino Médio, respectively.

Teachers working in primary school and secondary school have an average age around 50 years old and 40 years old, respectively, for both countries, Brazil and Spain. Concerning their degrees, in Spain, the primary school teachers had graduated with the specific formation of Primary Educator Teacher, except for one female teacher who had graduated in Pedagogy. Spanish Secondary School teachers' titles vary more: Mathematics (6), Engineering (5), Economics or Business Management (4), Architecture (3), Pedagogy (1), and Chemistry (1). In Brazil, Primary School teachers had graduated in Mathematics (4), Pedagogy (3), History (1), and Geography (1), and the teachers' trainings in Secondary School were in Mathematics (11), Chemistry (1), Law (1), Biology (1), and Engineering (1).

2.2. Data Collection

To collect data, we used a survey named "Gamification and Learning" (original name in Spanish "Gamificación y Aprendizaje"), proposed and validated by Cornellà [40]. According to Cornellà [40], the survey was validated though an expert judgment process, which included 17 experts. These people were distributed as experts in games and gamification (3), teachers with experience in applying gamification (7), experts in virtual learning environments (4), and experts in technology (3). The experts evaluated the adequacy between each block title and its questions, questions' relevance, and Likert scale adequacy. Cornellà [40] did corrections until the experts finally approved the survey.

We used Cornellà's [40] survey with few adaptations regarding our research objectives. For instance, we addressed gamification in mathematics in a general scope rather than focusing on virtual learning environments, as was originally the case. In addition, we included some questions related to STEAM Education.

It is noteworthy to say that the whole survey and its attachments were available in the language for each population sample: Catalan language for Spain (Catalonia Autonomy Community) and Portuguese language for Brazil. We divided the survey into three blocks.

Block A) These questions were designed to gather information about sample characteristics—age, courses, education level in which they work, and degree. Open-ended questions about prior experiences with gamification and STEAM Education were also included, so we could explore it qualitatively [41].

Block B) Two questions were included: the first is a Likert-type question scaled from 1 (not important) to 5 (very important), with a list of 18 general aspects regarding teaching the discipline of mathematics (e.g., content knowledge, ability to connect with students, method used in class, and others). In the second Likert question, teachers answered their (dis)agreement, ranging from 1 (strongly disagree) to 5 (strongly agree), to 21 statements about gamification in mathematics and interdisciplinary STEAM environment. Additionally, they evaluated a gamified activity framed in STEAM Education based on the activity Snap Hotels of Nguyen [42].

Block C) Four open-ended questions were included that were intended to explore other aspects that would permit identifying and evaluating teachers' predisposition and difficulties they consider they might encounter while employing activities in the interdisciplinary STEAM environment and/or gamified activities: (1) Teachers' beliefs about learning outcome differences between employing gamified and non-gamified activities. (2) Difficulties teachers believe they may encounter while engaging in a gamified activity. (3) Predisposition about using gamification in the next course. (4) How teachers envision the possibility of gamification in an interdisciplinary approach with STEAM areas.

2.3. Data Analysis

We analysed the Likert-type (close-ended) survey questions with descriptive statistics using frequency percentages for each item of scale. We used the R Studio Statistics program and its Likert library. This program exports data in the format of a horizontal bar graph, which permits observing respondents' positive and negative evaluation tendencies, but also neutral answer frequency, which makes it possible to perform group comparisons and address the occurrence of socially derisible responses (SDR) [43].

Analysis of the qualitative part of the study was based on constant comparisons according to grounded theory [41]. The following levels of analysis were considered. First, one author of this manuscript began by reading teachers' responses to become familiar with the content. Then, based on our research goal, we organised and structured information. At this first level, individual transcripts were arranged based on unit fragmentation or segmentation. While reading answers, teachers' dispositions to using gamification mathematics in education were noticed. For example: "*It motivates me a lot to think about implementing gamification in my class. I think it will arouse students' interest and passion*" (ProfEsp30). Raw data were transformed into useful data by first classifying and coding them.

Second, we established a group of categories. For example, in the first category, views of teachers were collected on how they use gamification in mathematics education. In this sense, the codification and categorisation of data were triangulated by comparing, ordering, and structuring to establish categories that allowed data to be compared.

Additionally, third, categories were renamed by the authors of the research, using the method of constant comparisons [41], which includes comparisons made between similarities, differences, and connections of the data. Units of information were scrutinised to see whether they clearly fell into a specific category. We further reflected on whether categories could be simplified and then grouped. We also considered the names and content of changed units, showing new relationships and possible new interpretations between categories. Thus, all aspects that prevented the definition of teachers' predispositions towards the use of gamification in mathematics education were renamed, eliminated, or simplified.

Again, it is worth noting that qualitative data were obtained in Catalan and Portuguese languages. Afterwards, these data were analysed by researchers who are native speakers of each one of these languages, so participants' original intentions could be better interpreted and captured in the analyses.

3. Results

The results follow the same order from the data collection instrument. According to the aim of our study, we analysed mathematics teachers' predispositions to carrying out gamification activities within STEAM education in primary and secondary school levels. First, we present results about the teachers' prior experiences in engaging in gamified activities and STEAM Education (Block A). Second, we present the results of closed-ended questions (Likert scale) in the form of two graphs: one about teachers' evaluations of the importance of general aspects related to classes of mathematics, and another graph about gamification in mathematics and an interdisciplinary STEAM environment. Additionally, they evaluated a gamified activity framed in STEAM Education based on the activity Snap Hotels of Nguyen [42] (Block B). Third and last, we wrote the results from analyses of four open-ended questions about gamification and STEAM Education (Block C). We present these results in the form of four tables (one referring to each question) structured with the names of corresponding categories in the first column; examples of teachers' response excerpts to qualify them in the second column; and columns with the quantification of the frequency that those categories appear in responses from Spain and Brazil.

3.1. Teachers' Prior Experiences with Gamified Activities and STEAM Education (Block A)

In this section, we present results about teachers' prior experiences with gamification in the current academic year. We present Table 2, which quantifies the proportion of teachers from Spain and Brazil who indicate having (or not having) conducted gamified activities in classes of mathematics in the current academic year (2020–2021 academic year or 2021 academic year in the Spanish or Brazilian calendar, respectively). In Spain, almost half of the total of teachers (46.9%) indicated they applied gamification in this academic year, with a higher frequency in the primary school (58.3%) compared to secondary school level (40%). In Brazil, on the other hand, the proportion of the country's total teachers who used gamification as a method in their classes in this academic year is a little more than a third (37.5%), with a much lower frequency in primary School (22.3%), which was less than half compared to the secondary school level (46.7%).

Table 2. Teachers who have previously carried out gamified activities in mathematics.

Have Carried out a Gamified Activity	Spain			Brazil		
	Primary School (10–12 Years)	Secondary School (12–16 Years)	Total	Primary School (10–14 Years)	Secondary School (14–16 Years)	Total
Yes	58.3% (7)	40% (8)	46.9% (15)	22.3% (2)	46.7% (7)	62.5% (15)
No	41.7% (5)	60% (12)	53.1% (17)	77.8% (7)	53.3% (8)	37.5% (9)
Total	12	20	32	9	15	24

A subsequent open-ended question asked for further explanation about the nature of the gamified activity from those teachers who positively answered to having applied one. In Spain, teachers reported that they applied gamification activities related to different resources and contexts: for example, a games table (2), online games (3), contests (2), and escape rooms (3). In Brazil, teachers mainly show that they employed table games (2) or online games (2). It should also be noted that around 16% of Spanish (5) and Brazilian (4) teachers considered gamification as manipulated didactic material, e.g. tangrams or multilink.

The proportion of teachers who indicated that they have worked with gamified activities in an interdisciplinary STEAM Education is much lower, as shown in Table 3: only 10 Spanish (31.2%) and 3 Brazilian (12.5%) teachers. Again, a subsequent open-ended question asked teachers to explain the nature of the gamified activities they applied within STEAM Education. In Spain, five teachers pointed to the STEAM areas they combined, while the other half did not specify. In Brazil, one teacher showed integrating mathematics and chemistry, while the others did not give more information. In addition, many have described STEAM without characteristics of gamification: for example, in the statement "*we photographed different objects in the school, then we analysed them and define each format and volume encountered*" (ProfSpain28).

Table 3. Teachers who have previously carried out gamified activities in mathematics framed in STEAM Education.

Have Carried out a Gamified Activity in STEAM Education	Spain			Brazil		
	Primary School (10–12 Years)	Secondary School (12–16 Years)	Total	Primary School (10–14 Years)	Secondary School (14–16 Years)	Total
Yes	33.3% (4)	30% (6)	31.3% (10)	11.1% (1)	13.3% (2)	12.5% (3)
No	66.7% (8)	70% (14)	68.8% (22)	88.9% (8)	86.7% (13)	87.5% (21)
Total	12	20	32	9	15	24

3.2. Teachers' Opinions about General Aspects of Math Class regarding Gamification and STEAM Education and Evaluating an Example of a STEAM Gamified Activity (Block B)

We present results from this subtopic in the form of graphs plotted in the R Studio Statistics program for Brazil and Spain combined. Following this, we address additional considerations about differences between the countries.

Figure 1 refers to a graph with Brazilian and Spanish teachers' evaluations of the importance of general aspects related to classes of mathematics. Before observing the graph content, it is worth explaining that each line in the graph is vertically organised. Additionally, each line contains a bar which may be dislocated from the central position according to how participants evaluated that corresponding element (Likert Scale 1 to 5): a high frequency of "Slightly important" and "Not Important" (1 and 2) make this line appear on the bottom of the graph, dislocating its bar to the left, and a high frequency of positive answers "Important" and "Very important" (4 and 5) makes this line appear on top of the graph and tends to dislocate its bar to the right, and this frequency percentage is shown on this side. The percentages of positive (4 and 5), neutral (3), and negative (1 and 2) answers are shown on the vertical axes in the left, middle, and right positions of the graph.

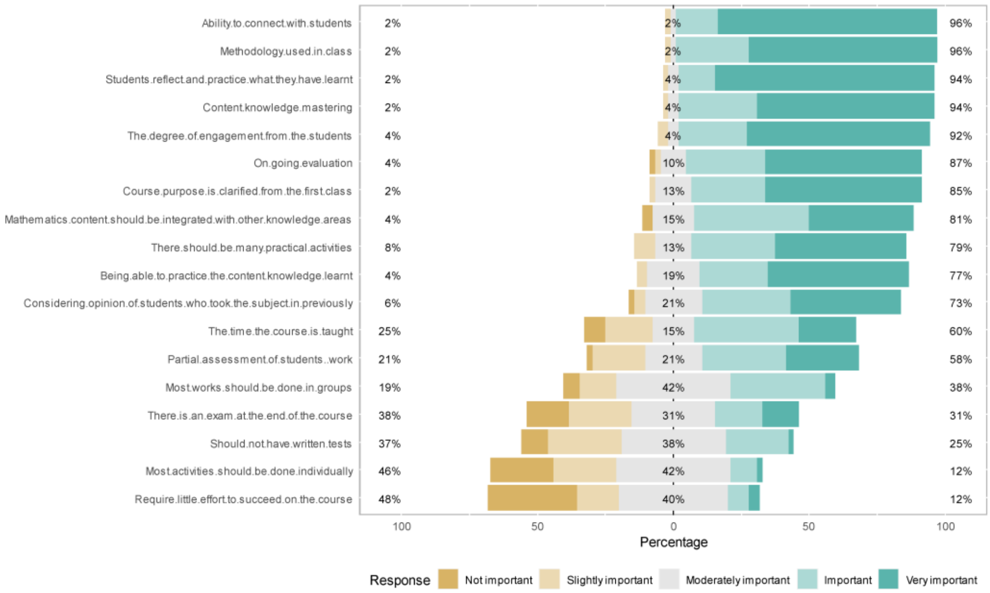

Figure 1. Brazilian and Spanish teachers' evaluation in the importance of general aspects related to classes of mathematics.

Finally, we address the content of the graph from Figure 1. First, we highlight aspects that teachers predominantly considered "Important" or "Very important": Ability to connect with students (96%), Methodology used in class (96%), Students reflect and practice what they have learnt (94%), Content knowledge mastering (94%), Students' engagement (92%), On-going evaluation (87%), Course purpose is clarified from the first class (85%), Mathematics content should be integrated with other knowledge areas (81%), There should be many practical activities (79%), Being able to practice the content knowledge learnt (77%), Considering the opinion of students who took the subject previously (73%), The time the course is taught (60%), and Partial assessment of students' work (58%).

The neutral answer "Moderately important" had a higher frequency percentage in the aspect Most works should be done in groups (42%), while it still presented a tendency towards a positive evaluation of importance (48%) compared to the negative pole (19%). In addition, the neutral answer had a slightly superior frequency in the aspect "Should not have written tests" (38%), but with a tendency towards a negative evaluation of importance (37%).

Teachers predominantly considered the following aspects "Not important" to "Slightly important": Requires little effort to succeed on the course (48%), Most activities should be done individually (46%), and There is an exam at the end of the course (38%).

Now, we draw attention to all items with a high frequency of the neutral answer "Moderately important". It had a frequency higher than 30% in the aspects Most works should be done in groups (42%), Most activities should be done individually (42%), Require little effort to succeed on the course (40%), Should not have written tests (38%), and There is an exam at the end of the course (31%).

In Figure 2, we present a graph with 21 statements about gamification in mathematics and the interdisciplinary STEAM environment. Additionally, a gamified activity framed in STEAM Education based on the activity Snap Hotels of [42] is evaluated. The graph construction and its structure are similar to Figure 1, with the difference that Likert scale refers to (dis)agreement to statements from each line, ranging from "Strongly disagree" (1) to "Strongly agree" (5).

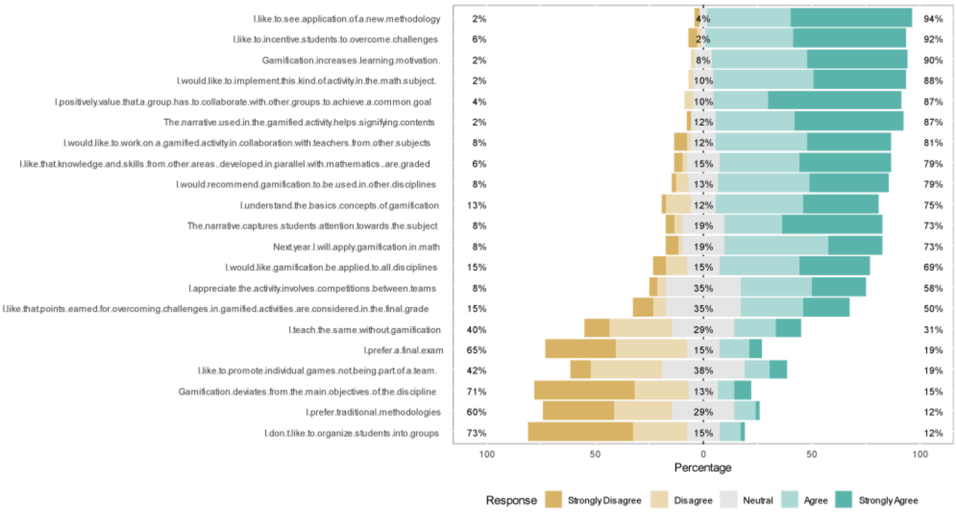

Figure 2. Teachers' opinions about gamification in mathematics and STEAM Education. Additionally, evaluation of a gamified activity framed in STEAM Education based on the activity Snap Hotels of Nguyen [42].

Teachers predominantly answered "Agree" or "Strongly agree" (4 and 5) to the statements: I like to see application of a new methodology (94%), I like to incentivize students to overcome challenges (92%); Gamification increases learning motivation (90%); I would like to implement this kind of activity in math subjects (88%); I positively value that a group has to collaborate with other groups to achieve a common goal (87%); The narrative used in the gamified activity helps signifying contents (87%); I would like to work on a gamified activity in collaboration with teachers from other subjects (81%); I like that knowledge and skills from other areas, developed in parallel with mathematics, are graded (79%); I would recommend gamification to be used in other disciplines (79%); I understand the basic concepts of gamification (75%); The narrative captures students' attention towards the subject (73%); Next year I will apply gamification in math (73%); and I would like gamification to be applied to all disciplines (69%). However, the following two statements still conserve a frequency tendency on the agreement pole: I appreciate the activity involves competitions between teams (58%) and I like that points earned for overcoming challenges in gamified activities are considered in the final grade (50%); it is worth noting the high frequency of the neutral answers, both of which were 35%.

From the bottom of the graph, we observe the statements to which teachers more frequently answered "Disagree" and "Strongly Disagree" (1 and 2). These statements include I do not like to organise students into groups (75%); Gamification deviates from the major objectives of the discipline (71%); I prefer a final exam (65%); I prefer traditional methodologies (60%); I like to promote individual games (not being part of a team) (42%); and I teach the same without gamification (40%).

Highlighting a high frequency of neutral answers, as reported above, the statements from the agreement pole I appreciate the activity involves competitions between teams and I like that points earned for overcoming challenges in gamified activities are considered in the final grade both had a 35% frequency of neutral answers. Some statements from the disagreement pole also had a high frequency of neutral answers: I like to promote individual games (not being part of a team) (38%); I prefer traditional methodologies (29%); and I teach the same without gamification (29%). No statement presented a frequency of neutral answers higher than the options of agreement or disagreement.

3.3. Teachers' Opinions about the Contrast between Gamified and Non-Gamified Activities, Issues in Gamification, and Gamification in STEAM Education (Block C)

Finally, yet importantly, we describe the results of the analyses of answers of four open-ended questions from Block C. We present these results in the form of four tables (one per question): the first column includes categories; the second column examples of teachers' response excerpts; and finally, columns with the frequency of responses from Spain and Brazil. These questions, presented below, intended to explore and identify what mathematics teachers' think about the differences between gamified and non-gamified activities, the difficulties of gamification in mathematics, their predisposition toward employing gamification, and how they envision the possibility of gamification in an interdisciplinary approach with STEAM areas.

1. Which differences do you think may exist between learning outcomes and learning processes when we compare a gamified and a non-gamified activity?

The analysis of answers to this question resulted in three principal categories of teachers' beliefs about the differences between gamified and non-gamified activities, as seen in Table 4. In the category Positive difference, around 81.1% of Spanish and 76.9% of Brazilian teachers considered differences by pointing to the advantages of gamification. On the other hand, and with a much lower frequency, in the category Negative difference, around 8.11% of Spanish and 3.85% of Brazilian teachers also considered the existence of differences, but in this case, pointing to the disadvantages of gamification. Additionally, third, in the category Not different, a few teachers considered no differences between gamified and non-gamified activities, 2.7% in Spain and no teacher from Brazil. The percentage of non-respondents in Brazil is more than double that of Spain: 19.2% and 8.11%, respectively.

Table 4. Teachers' beliefs about learning outcome differences between employing gamified and non-gamified activities.

Gamified versus Non-Gamified Activity		Teachers' Answers Excerpts	Frequency per Country	
			Spain	Brazil
Positive view towards gamification	Affective domain	"I believe student's interest makes them more open to rules, content and listening to teacher and colleague" (ProfBra20).	32.4%	34.2%
	Cognitive domain	"The difference remains in a manner to approach to content: students who learn with gamification have better memorisation and good memories about how they have learnt" (ProfEsp05).	10.8%	11.4%
	Skills acquisition	"Gamified activity enables logical reasoning skills development, contextualisation and interdisciplinarity" (ProfBra19).	27%	26.2%
	Did not specify	-	10.8%	3.85%
No differences		"They [gamified and non-gamified activities] are just methodologies, which can address content (vehicle). I do not think using one would be better than the other" (ProfEsp07).	2.7%	-
Negative view towards gamification		"Gamifying means providing time to students to build knowledge autonomously, make questions, analyse alternatives. Theoretically that is great, but it creates difficulties" (ProfEsp16).	8.11%	3.85%
Did not answer		-	8.11%	19.2%

Within the category Positive differences, we could induce subcategories regarding differences related to Affective domain, Cognitive domain, Skills acquisition, and Not Specified. The frequencies of these subcategories are similar between Spain and Brazil, aspects of Affective domain and Skills acquisition being present in approximately 30% of responses, and around 10% from the subcategory Cognitive domain.

2. Which difficulties do you believe one may face while engaging in a gamified activity in mathematics?

The results of the analysis of responses to this question resulted in the creation of four categories of issues, as displayed in Table 5, that teachers indicate are related to employing gamified activities in mathematics: Planning difficulties, Class management difficulties, Deficient teacher training, and Educational community reticence.

Table 5. Difficulties teachers believe they may encounter while engaging in a gamified activity.

Beliefs about the Difficulty in Gamified Activity in Mathematics	Teachers' Answer Excerpts	Frequency per Country	
		Spain	Brazil
Planning difficulties	"The required time complete it in class. If the class duration is of one hour, often there is no time to finish the activity. Many centres have limited resources" (ProfEsp05).	34.3%	34.6%
Class management difficulties	"Some students may dislike it, or get too anxious/nervous; others might be so competitive that they have to be redirected" (ProfEsp06).	25.7%	11.5%
Deficient teacher training	"Little teachers' experience while designing gamified activities and managing tools that would facilitate this task" (ProfEsp11).	20%	19.2%
Educational community reticence	"Breaking with traditional approaches: the biggest difficulty is being open to novelty since it means a greater expenditure of energy, many teachers will think like that" (ProfBra11).	-	15.4%
Did not answer	-	20%	19.2%

As a result, we detected some discrepancies between Brazil and Spain. Although the similarity in the frequency of respondents who pointed to issues within planning difficulties was approximately 34%, when we scrutinise the responses, we noticed differences. With Brazil, half of these responses suggested a lack of resources/investment as an issue when employing gamification in mathematics, e.g., in the excerpt: "*Since I work in a public school, we deal with limited resources. Frequently I spend my money to apply games or other methodologies*" (ProfBra20). Spanish teachers centred their attention on difficulties with the design and evaluation of gamified activities.

In the second category, Class management difficulties, the content of answers is similar for the countries, but it is more prominent with Spain, where the frequency is more than double that of Brazil: 25.7% and 11.5%, respectively.

We highlight another difference between the studied countries in the category Educational community reticence. A significant proportion of Brazilian teachers, 15.4%, show they are likely to face some reticence among peers or the scholar board when employing non-traditional educational methodologies such as gamification. Meanwhile, no Spanish respondent demonstrated this kind of difficulty.

Similarly, with around 20% of response frequency, Brazilian and Spanish teachers show Deficient teacher training as a difficulty in pursuing gamification in their classes. Approximately 20% of Brazilian and Spanish teachers did not answer this question.

3. How do you evaluate the possibility of using gamification as a teaching method in classes of mathematics? What are your feelings about it?

We could classify the answers from these questions into the categories Favourable predisposition and Unfavourable predisposition regarding teachers' intentions to attain gamification in their disciplines. Inside the category Favourable predisposition, we could distinguish three subcategories, as shown in Table 6, that qualify this predisposition: without indicating reticence, with reticence about deficient teacher training, and with reticence about lack of resources.

Table 6. Teachers' predisposition about using gamification in the next course.

Predisposition		Teachers' Answer Excerpts	Frequency per Country Spain	Brazil
Favourable	Not indicating major concerns	"It motivates me a lot to think about implementing gamification in my class. I think it will arouse students' interest and passion" (ProfEsp30).	43.8%	54.2%
	but showing insecurity or concerns about lack of formation	"I want it, but it generates in me some sense of losing control. Perhaps, gradually, it can be achieved" (ProfEsp23). "I would love it, but I am conscious I should receive training previously" (ProfEsp19).	34.4%	8.33%
	but showing concerns about lack of resources	"Again we face the difficulty of time and investments" (ProfBra22).	-	4.17%
Unfavourable		Little possibility regarding the pandemic scenario (ProfBra03).	-	8.33%
Did not answer		-	21.9%	25%

Most teachers, approximately 70% for both countries, who replied to this question show a favourable predisposition to employing gamification in their classes. Some of them, on the other hand, question this predisposition. For instance, 34.4% of Spanish teachers suggest that teacher training would be necessary, while in Brazil, only 8.33% pointed in this direction. Again, lack of resources/investment appears to be an issue that differentiates the countries, since only Brazilian teachers, 4.17%, showed a favourable predisposition but reticence considering this reason. Only Brazilians answered with an unfavourable predisposition, with an 8.33% frequency of responses in this country, e.g., justified by the pandemic scenario of COVID-19: "*I see little possibility, given the current pandemic scenario*" (ProfBra03).

4. How do you evaluate, in a gamified activity, the possibility of providing an interdisciplinary environment with some (or all) STEAM areas?

We categorised the results of this question into Possible and Not possible, referring to providing STEAM interdisciplinary environments through gamification. Most teachers in Brazil, 81.8%, envision this possibility, while in Spain, the percentage is 50%, as shown in Table 7.

Table 7. Teachers' beliefs about providing STEAM interdisciplinary environments throughout gamification as a teaching method.

Gamification as a Method for STEAM Education	Teachers' Answers Excerpts	Frequency per Country Spain	Brazil
Possible	"It is a good idea to evaluate when next academic year begins" (ProfEsp32).	50.0%	81.8%
Not possible	"Little possibility, since there is a curriculum to be accomplished" (ProfBra03).	28.1%	9.09%
Did not answer	-	21.9%	9.09%

Those who replied no possibility presented justifications for being sceptical about this association of gamification and STEAM Education, such as deficient teacher training—"*Currently, I see it impossible. It would be necessary to train all teachers before working collaboratively and in a multidisciplinary approach*" (ProfEsp05) —being difficult to assess—"*It is complex to know what to be evaluated and where it focuses on each discipline*" (ProfEsp07) —

difficulty in coordinating different disciplines, especially in the secondary school level—"*It requires much coordination and sometimes it is hard to gather*" (ProfEsp22) —or lack of adequate time—"*Feasible, but I imagine that organising it requires time that we don't have*" (ProfEsp15). In Spain, we also observed teachers from primary school, who regularly already have the same professional teaching subjects from different knowledge areas, evaluate this possibility more positively. Half of the teachers from secondary school did not see it as possible because, among the difficulties mentioned before, they found it hard to coordinate along with teachers in other STEAM areas.

4. Discussion

In this article, we analysed teachers' opinions and predispositions about gamified activities and the STEAM education approach. According to the literature review, mathematics is one of the STEAM areas that has been least considered so far in gamification (4). Studies of gamification in mathematics have mainly focused on the effect of this method on students' learning outcomes [21–24,28], reporting data, to some extent divergent, related to students' engagement, motivation, or satisfaction [1,2,24].

However, what is the role of mathematics teachers' predispositions and opinions towards gamification? What effects can those teachers' predispositions and opinions have on students' levels of engagement, motivation, and satisfaction? As previously shown, few studies in the literature address teachers' opinions and predispositions about the use of gamification in mathematics classes [33–35], and even fewer in the Spanish and Brazilian panorama.

Data from our study help to fill this literature gap. The first revealing result is that only half of the Spanish teachers and two-thirds of the Brazilian teachers who took part in our study have used gamification in mathematics. Important differences between the two countries emerge when we observe gamification. With Spain, teachers employed a wider variety of resources; comparing students' ages, while in Spain, they apply gamification more in the primary school compared to secondary school level, in the Brazilian context, it happens the other way around.

The results confirm increasing academic attention towards both gamification and competency-based education [33]. Currently, it appears slightly more palpable in Spain than in Brazil. The number of Spanish and Brazilian teachers who have worked with gamification within the STEAM Education approach is much lower, also observing some confusion around the concepts of both gamification [24,25] and STEAM.

Regarding teachers' opinions about using gamification, mathematics teachers at primary and secondary schools in both countries have highlighted that they consider mastery of content as essential in gamified activities, as well as other elements such as reflective and critical thinking skills [33] or engagement [34]. One aspect mathematics teachers least valued was that activities should be done individually in gamification. These data reinforce the findings of Martí-Parreño et al. [33] and Allabasi [34], which suggest that teachers believe gamification encourages team working and oral communication skills, along with social interaction.

Our findings address how mathematics teachers perceive differences and difficulties while using gamified activities within the STEAM Education approach, compared to more traditional ones. The results show, at first sight, a high percentage of teachers (around 80%) who think this kind of activity has positive effects on students' development, improving their affective domain toward mathematics and required skills for mathematical competency. Based on teacher opinions, we can complement the results from previous studies about students' affective domain, which suggests gamification alone may not sustain students' interest and motivation in satisfaction levels [1]. In this sense, we can add that gamification could be carried out in STEAM Education. In order for those features of the affective domain to be more highly attained, this approach to gamified activities needs to be authentic to provide an interdisciplinary environment.

Since teachers believe gamification in a STEAM approach promotes skills development for mathematical competency, we found the congruency that both teachers and policy makers should be encouraged to increase the use of gamification-based programs to develop students' competencies [33]. Concerning the main difficulties, we observed similarities and differences between the two studied populations: teachers from both countries misunderstand the concepts of gamification and STEAM, and they indicate insecurity and a lack of training in planning gamified activities, which points to the necessity for specific teacher training programs [35,36].

In the Brazilian case, half of the teachers refer to the lack of resources as the reason for not carrying out gamification in their classes, but we recall from the literature that gamification can be done with low investment in resources [19]. Since these teachers reported almost no prior experiences with gamification, and those few who reported included examples of activities that are not considered gamification, such as the use of manipulative objects, this leads to the interpretation that this complaint about lack of resources might be a clue about a misunderstanding of the concept of gamification.

Still focusing on the Brazilian context, teachers showed concerns about reluctance/resistance from teaching staff or school management when they want to carry out activities with methodologies such as gamification. Therefore, this seems to show that experts should design teacher training within models that consider the transformation of teachers' beliefs, such as with the realistic-reflective training model [44], to address this resistance.

Finally, in our study, we have also investigated teachers' predispositions to carrying out gamification activities in interdisciplinary environments with STEAM disciplines. The results from a closed-ended question show that around 80% of Brazilian and Spanish teachers agreed with the statements "*I would like to work on a gamified activity in collaboration with teachers from other subjects*" and "*I like that knowledge and skills from other areas, developed in parallel with mathematics, are graded*". Notwithstanding, further exploration in an open-ended question showed that this same favourable disposition of 80% only remained for Brazil. In Spain, there are differences between primary teachers, who are generalists and teach all STEAM subjects, and secondary teachers, who are specialists and only teach mathematics. In primary school, teachers see it as possible, but in secondary, more than half of the teachers do not see it as possible because they find it difficult to coordinate with teachers from other STEAM areas. This result confirms the findings of Part et al. [38].

The literature about Likert scales warns that people are likely to choose neutral options for reasons other than being neutral about the topic—for example, when respondents have no interest, or when they want to provide a socially desirable response (SDR): to respond according to what they imagine others expect them to answer or to avoid options that they think peers or any reference group would frown upon [43]. Neutrality in the agreement was around 40% with questions that address students' distribution: "Most works should be done in groups" or "Most activities should be done individually". Neutrality was around one-third of the responses when we scrutinised the evaluation and the statements "Should not have written tests", "There is an exam at the end of the course", and "Points from the gamified activity to be considered in the final grade". All this points to the possibility that teachers may give an SDR of a favourable disposition towards new methodologies such as gamification when they are not sure if they agree with it. Another statement directs us to this conclusion: almost one-third of teachers responded neutrally to "I prefer traditional methodologies".

We highlight that in open-ended responses, only 43.8% of Spanish and 54.2% of Brazilian teachers stated a favourable predisposition towards gamification without reticence. Reticence, whatever its form, might underpin indisposition. Another consideration could be due to the fact that 21.9% of Spanish and 25% of Brazilian teachers did not answer, while the question straightforwardly asked them to evaluate the possibility of using gamification as a teaching method in classes of mathematics. Not answering it may also point to some indisposition.

Our results show that it seems necessary to add a fifth characteristic that should be fulfilled, so that mathematics education could be promoted through the gamification method, to those already indicated by Muñoz et al. [24]: interdisciplinarity. Since teachers present a conceptual misunderstanding of gamification and STEAM Education, they report insecurity and lack of training for engaging in such educational methodologies [33–37]. They also may have an underpinning reluctance to designing and carrying out gamified activities within interdisciplinary approaches [36]. Along with this observation of ambiguous speech in which they are theoretically favourably considering new methodologies, they also show traits of indisposition when they think about actually applying them. In conclusion, there is an urgency for designing teacher-training programs framed within models that intend to transform professional competency by reflecting on teachers' prior experiences and beliefs about gamification and STEAM Education. Therefore, we recommend researchers to explore teacher-training programs in gamification and STEAM Education within a realistic-reflective framework, considering the possibility of distance learning modalities, especially for big countries such as Brazil [45]. The results qualitatively show interesting insights into teacher perceptions on gamification and STEAM Education in the countries of Brazil and Spain. Notwithstanding, the research has a limitation: the sample is small, and therefore the comparative results between the two populations cannot be generalised. Further studies with larger samples are necessary.

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ARTICLE C

Teachers’ predispositions toward playful learning

Implications for teacher training

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Teachers' predispositions toward playful learning: implications for teacher training

Jefferson Rodrigues-Silva[i]
Federal Institute of Minas Gerais, Arcos, MG, Brazil
University of Girona, Girona, Catalonia, Spain

Ángel Alsina[ii]
University of Girona, Girona, Catalonia, Spain

Abstract
During Covid-19, schools adopted Emergency Remote Teaching, and teachers had the opportunity to use methodologies based on playful learning (free and guided play, etc.). In this context, quantitative research was designed on the predispositions of 157 Brazilian teachers towards playful learning, comparing teaching experience, educational level and type of institution. The results obtained from a previously validated questionnaire showed the teachers of "*Fundamental I*" (6-10 years) and municipal schools are more predisposed to playful learning, use it more frequently and consider it more suitable for Emergency Remote Teaching. On the other hand, teachers from "*Municipal*" and "*Estadual*" public schools reported less support in teacher training focused on didactic diversification and perceived more difficulties during the Emergency Remote Teaching. In addition, these difficulties were significantly related to the non-diversification of activities in the period.

Keywords
playful learning; Emergency Remote Teaching; Teachers' predispositions; teacher training.

Predisposições dos professores sobre a aprendizagem lúdica: implicações para a formação docente

Resumo
Durante a Covid-19, as escolas adotaram o Ensino Remoto Emergencial e os professores tiveram a oportunidade de utilizar metodologias baseadas na aprendizagem lúdica (brincar livre e guiado, etc.). Nesse contexto, desenvolveu-se uma pesquisa quantitativa sobre as predisposições de 157 professores brasileiros para a aprendizagem lúdica, comparando--se experiência docente, nível educacional e tipo de instituição. Os resultados obtidos a partir de um questionário previamente validado mostraram que os professores do ensino fundamental I (6-10 anos) e das escolas municipais estão mais predispostos ao aprendizado lúdico, o utilizam com mais frequência e o consideram mais adequado ao Ensino Remoto de Emergencial. Por outro lado, os professores das escolas municipais e estaduais relataram menos apoio na formação docente voltada para a diversificação didática e perceberam mais dificuldades durante o Ensino Remoto de Emergencial. Além disso, essas dificuldades estão significativamente relacionadas a não diversificação das atividades no período.

Palavras-chave
aprendizagem lúdica; Ensino Remoto de Emergencial; predisposição dos professores; formação de professores.

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Predisposiciones del profesorado sobre el aprendizaje lúdico: implicaciones para la formación docente

Resumen
Durante la Covid-19, las escuelas adoptaron la Enseñanza Remota de Emergencia y los docentes tuvieron la oportunidad de usar metodologías basadas en el aprendizaje lúdico (juego libre y guiado, etc.). En este marco, se diseñó una investigación cuantitativa sobre las predisposiciones de 157 profesores brasileños hacia el aprendizaje lúdico, comparándose la experiencia docente, el nivel educativo y el tipo de institución. Los resultados obtenidos a partir de un cuestionario previamente validado mostraron que los profesores del "Fundamental I" (6-10 años) y de escuelas municipales están más predispuestos al aprendizaje lúdico, lo utilizan más frecuentemente y lo consideran más ajustado a la Enseñanza Remota de Emergencia. Por otro lado, los docentes de las escuelas municipales y estaduales reportaron menor apoyo en la formación docente enfocada a la diversificación didáctica y percibieron más dificultades durante la Enseñanza Remota de Emergencia. Además, estas dificultades se relacionaron significativamente con la no diversificación de las actividades en el periodo.

Palabras clave
aprendizaje lúdico; Enseñanza Remota de Emergencia; predisposición de docentes; formación de profesores.

1 Introduction

Play is recognised as a freedom right in the Brazilian Child and Adolescent Statute (BRASIL, 1990). This concern is shared globally, as observed in the Convention on the Rights of the Child (UN, 1989). If the importance of play is well addressed in childhood, it seems to dissipate as people get older. Some adults may consider playing an insignificant component of their world (TEGANO; GROVES; CATRON, 1999). It sometimes is even viewed as the antithesis of professionalism and adult life (VARELA; FRAGUELA-VALE; LÓPEZ-GÓMEZ, 2021).

However, play is a hard concept to define (MITTON; MURRAY-ORR, 2022; ZOSH *et al.*, 2018). Discussions around it are usually vague and void of nuance (ZOSH *et al.*, 2018). Some people consider playing exclusively as free play, which means unstructured activities initiated and self-directed by children (MITTON; MURRAY-ORR, 2022). On other occasions, playing is referred to as a synonym for games (MINEIRO; D'ÁVILA, 2019), wherein voluntary participants agree on structure and rules and are driven by pure entertainment without extrinsic goals such as learning.

If, on the one hand, joy provided by play already justifies its value (if it had to be defended in the first place). On the other hand, play goes beyond the pursuit of joy. Play

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is an intrinsic social and human activity established through interaction with the world (SILVESTRE; BARBOSA, 2022). In this sense, Heljakka (2021) investigated a social phenomenon in Finland during the pandemic of Covid-19. Adults and children enrolled in a social play of displaying teddy bears in visible places such as windows and gardens. People created different compositions with those toys and shared many photos on social media. The author highlighted playfulness as resilience. In this case, play aimed to mitigate the adverse effects of social distancing. Through this trend, people could reconnect with each other and express feelings, such as positivity and willingness to contribute to the common good.

In this way, despite a disinterested first look, playfulness is also addressed with purposeful outcomes. Accordingly, it is a topic of increasing interest in education (SANTOS; PEREIRA, 2019). A plethora of studies argue for the positive impact of playfulness on students' motivation, learning content knowledge, skills (ZOSH *et al.*, 2018) and behaviour change, such as fostering a positive attitude toward reading books (QUIXADÁ; LINS; TAVARES, 2018).

The bulk of the research literature on playful learning is concentrated in childhood (ALSINA, 2004; MINEIRO; D'ÁVILA, 2019; MITTON; MURRAY-ORR, 2022; SILVA, N.; SILVA, J.; COSTA, 2020), and accordingly, most teachers assert a playful role in child life (OLIVEIRA; SILVA, 2016). On the contrary, little research has been conducted considering the impact on older children or adults (KING, 2018).

In this research, we argue that play constitutes individual, social, cultural (SANTOS; PEREIRA, 2019), and intergenerational (HELJAKKA, 2021) enterprise accessed through different forms (SANTOS; PEREIRA, 2019). In this sense, play is understood as a spectrum (ZOSH *et al.*, 2018) which goes from unstructured to formal and organised activities. Playful encompasses free play at one end, passing through activities such as guided play, games, gamification (LÓPEZ; RODRIGUES-SILVA; ALSINA, 2021), and theatre (MORAL-BARRIGÜETE; MASSÓ GUIJARRO, 2022) until playful direct instruction at the other end.

This broader view of play as a spectrum allows it to be considered across educational levels (MITTON; MURRAY-ORR, 2022). Play becomes more structured as we progress in the academic percuss (MITTON; MURRAY-ORR, 2022; TEGANO;

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GROVES; CATRON, 1999). So free play might be more suitable in early childhood, and games/gamification may gradually gain space with older students.

Teachers are likely to understand the concept of playfulness differently (KHALIL *et al.*, 2022), and they may not have this wide-ranging understanding of it. Tegano, Groves and Catron (1999) found a strong positive correlation between teachers' playfulness as a personal trait and their ambiguity tolerance. They concluded that playful teachers might even create ambiguous situations to support students' curiosity and risk-taking.

Playfulness requires appropriate planning to contextualise knowledge and achieve learning goals (TOMAZ DE AQUINO *et al.*, 2020). Mitton and Murray-orr (2022) enrolled in an in-depth of one middle school teacher's practices with a focus on how she infuses flay into learning. They observed three main aspects that should be nurtured in play infusion: belief in students' efficacy, relationship with students and families, and excitement. Moreover, the authors concluded that teachers need, beyond this pedagogical knowledge, creativity to infuse play and create optimum learning conditions.

Teachers consider the infusion of play a complex task (NDLOVU; MNCUBE, 2021). They report weak theoretical scaffolding (KHALIL *et al.*, 2022; OLIVEIRA; SILVA, 2016) and a low ability to design play-based learning (KHALIL *et al.*, 2022). Poorly planned environments lead to chaos, while this confusion and disharmony do not give children the opportunity for creative growth (TEGANO; GROVES; CATRON, 1999).

As stated before, the play might be a coping mechanism for increased perseverance in challenging times such as pandemics (HELJAKKA, 2021). In this sense, playful learning seems reasonable to be adopted during Emergency Remote Teaching (ERT). However, teachers and educators expressed that their motivations for play decreased due to the ERT context imposed by the pandemic period (KHALIL *et al.*, 2022).

Covid-19 lockdown resulted in restrictions on conventional spaces for play and shrunk to the domestic sphere (HELJAKKA, 2021). It changed the kind of game, limiting physical games, principally those that require displacement and object manipulation (VARELA; FRAGUELA-VALE; LÓPEZ-GÓMEZ, 2021). Varela, Fraguela-Vale, and López-Gómez *et al.* (2021) studied the lockdown effect on time dedicated to games in Spain. They concluded that the time of playing games increased notably but especially concerning digital ones. Schools increased assistance to families with games. However,

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only half of the families received recommendations and game-related school assignments.

Although playful learning is a source of enjoyment for both teachers and students (KHALIL *et al.*, 2022), teachers' predisposition encounters contradictory landscapes: playful learning is highly recommended in education, but the vague definition may prevent them from considering it throughout the continuum of educational levels. Teachers may face other difficulties, such as inadequate time to enrol in playful activities (SANTOS; PEREIRA, 2019), curriculum inflexibility, and insufficient resources and physical space (KHALIL *et al.*, 2022). Additionally, the Covid-19 lockdown reduced spaces available for playing, which became mainly restricted to the domestic sphere (HELJAKKA, 2021). Consequently, teachers' opinions regarding playful learning in this context are unclear.

According to all presented above, this research should explore Brazilian teachers' opinions, training and application of playful learning, bearing in mind the ERT adopted during the pandemics of Covid-19. We aim to make comparisons of those aspects regarding their teaching experience, educational level, and institution type.

Next, the article presents the research methods with information about the questionnaire we administered, the sample characteristic, and the data analysis procedure. Results and discussions follow the order of topics from this data collection instrument.

2 Methods

According to the presented objective, this research was developed with a quantitative approach, and a cross-section design, which means data was collected once at a time (LAWSON; FAUL; VERBIST, 2019).

2.1 Data collection instrument

As an instrument, we administered an online survey adapted from Fernandes, Santana and Rodrigues-Silva (2022). Those authors also explored Brazilian teachers' opinions on playful learning in ERT, focusing on teachers of History.

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Table 1 presents a summary of the instrument used in this research. It has four blocks, namely: Sample characteristics, Playful learning and ERT, Teacher training centred on teaching methods diversification, and use of playful activities.

Table 1 – Instrument summary of topics

Block	Variable	Item	Variable type
Sample characteristic	Teaching experience	1	Categorical
	Educational level	1	Categorical
	Institution type	1	Categorical
Playful learning and ERT	Predispositions toward playful learning	4	Scale (aggregation)
	Playful learning suitability in ERT	4	Scale (aggregation)
	Difficulties in ERT	13	Scale (aggregation)
	Teaching method diversification in ERT	14	Scale (aggregation)
Teacher training centred on teaching methods diversification	Teacher training provided by the institution*	2	Ordinal (Likert)
	Teacher training searched autonomously*	2	Ordinal (Likert)
Use of playful activities	Use of playful activities*	2	Ordinal (Likert)

* Repeated measure of the variable considering before the pandemics and during ERT.
Source: Own elaboration (2022).

Each variable will be further explained in the topic of data analysis. However, at this point, some instrument features are worth highlighting. For example, sample characteristics comprise the independent variables used to establish comparison groups: teaching experience, educational level, and institution type. Moreover, variables in the second block were obtained from an aggregation of Likert questions. Difficulties in ERT refer to a list of items teachers were likely to face during the ERT: poor internet access and excessive workload. Teaching method diversification in ERT refers to a list of strategies, e.g., games, seminars, discussion boards.

This survey was publicised through online channels such as email lists and social media and focused on teachers from basic education.

2.2 Sample

After approximately one month of divulgation, 157 Brazilian teachers volunteered to participate in the research. All of them firmed a consent term and were considered in

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this research. Those participants are in-service teachers from different subjects. Their main characteristics are summarised in Table 2.

Table 2 – Sample characteristics (independent variables for comparison groups)

Sample characteristic (independent variable)	Level	N	%
Teaching experience	Novice (up to 5 years)	52	33%
	Experienced (more than 5 years)	105	67%
Educational level	*Ensino Fundamental I* (students' age: 6 – 10 years)	39	25%
	Ensino Fundamental II (students' age: 11 – 14 years)	48	31%
	Ensino Médio (students' age: 15 – 17 years)	70	45%
Institution type	Private school	28	18%
	Municipal (Public schools funded at the town level)	44	28%
	Estadual (Public schools funded at the state level)	60	38%
	Federal (Public schools funded at the federal level)	25	16%

Source: Own elaboration (2022).

As stated earlier, those characteristics will be addressed as independent variables. So, we better explain how their levels were constituted. Teaching experience has two levels: novice, a newly qualified teacher with up to five years of professional teaching practice (MAKOA; SEGALO, 2021); and experienced teacher, with more than five years of teaching. The Educational level variable has three divisions established according to the Brazilian Curriculum (BRASIL, 2018). Those educational levels can be approximated to the British curriculum, for example, as Primary School corresponding to "*Ensino Fundamental I*" and "*Ensino Fundamental II*" and Secondary School being analogous to "*Ensino* Médio". In Brazil, education responsibility is shared between towns, states and federal levels. For instance, tows are responsible to guarantee people access in *"Fundamental"* level (BRASIL, 1996).

2.3 Data analysis

During the analysis, Statistical Package for the Social Sciences (SPSS) served as the computational tool for the statistics. The significance α of 5% was set as the threshold in all statistical tests throughout this research.

The first instrument block refers to playful learning and ERT. In this part, ordinal variables (Likert) were aggregated into four scale variables: predisposition toward playful learning (ranging from 13 to 65), difficulties in ERT (ranging from 4 to 20), teaching

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method diversification in ERT (ranging from 14 to 70) and playful learning suitability in ERT (ranging from 4 to 20). Then, a Pearson r was calculated to observe the relation between them.

Afterwards, we conducted One-Way ANOVA in those same four variables to verify differences considering the independent variables. Whenever Levene's test was significant, we conducted the non-parametric options: Wilcoxon Mann-Whitney Test for two groups; or Kruskal-Wallis Test for more than two groups (LAWSON; FAUL; VERBIST, 2019).

Next, elements from the two last instrument blocks are addressed as ordinal variables. The third block refers to teacher training centred on diversifying teaching methods. The training is specified whether it was provided by the institution or searched autonomously. Finally, the fourth block refers to the use of playful activities. At this point, the analysis addressed data which were answered considering the period before the pandemic. Non-parametric options, Wilcoxon Mann-Whitney Test (for two groups) or Kruskal-Wallis Test (for more than two groups), were applied because of the ordinal nature of those independent variables.

Despite the cross-sectional research design, participants were to answer questions from those two last instrument blocks considering the temporal frames: before the pandemics and during the ERT. In this case, we highlight data concerning the period before pandemics relies on teachers' memory. However, pandemics could not be anticipated in this research. Therefore, this strategy allowed us to do a virtual pre-post design. Wilcoxon Signed Ranks Tests were suitable for within-subject paired comparisons (WILCOXON, 1945). Following, we present the results obtained from those analyses.

3 Results

Results are presented following the sequence in which data was analysed. As stated before, questions of the first block of the instrument were aggregated into four scale variables. Table 3 presents the calculus of the Person r coefficient, which indicates the relationship between them.

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Table 3 – Relationship between teachers' opinions about playful learning, Teaching method diversification, and ERT. Person r coefficient

	Predispositions toward playful learning	Playful learning suitability in ERT	Difficulties in ERT	Teaching method diversification in ERT
Predisposition toward playful learning	1	**.702****	-.014	.116
Playful learning suitability in Emergency Remote Teaching (ERT)	**.702****	1	-.135	**.269****
Difficulties in ERT	-.014	-.135	1	**-.324****
Teaching method diversification in ERT	.116	**.269****	**-.324****	1

** Correlation is significant at the 0.01 level (2-tailed).
Source: Own elaboration (2022).

Results indicate a significant strong positive relationship between teachers' predisposition toward playful learning and how they value the Playful learning suitability in ERT (r = .702, p = 001). This result is relatively straightforward. Teachers with a higher predisposition toward playful learning consider it an important approach during the ERT. Moreover, a significant moderate positive points to the relationship between the Playful learning suitability in ERT and teaching method diversification in ERT (r = .269, p = 001). Again, teachers who diversify their teaching in the ERT consider playful learning as an essential approach during this period.

The variable about difficulties in ERT was not statistically related to teachers' predisposition to playful learning or teachers' evaluation of the Playful learning suitability in ERT. However, the variable on difficulties in ERT was negatively related to teaching method diversification in ERT (r = -.324, p = 001). So, results suggest teachers tend to diversify their teaching less as they face more difficulties during this period.

Cautiously, a global insight can be drawn if we observe the means of those four elements divided by the number of original elements. Predispositions toward playful learning had a mean of 4.4. Similarly, playful learning suitability in ERT had a mean of 4.1. Those values are closer to the fourth element of the original Likert scale, pointing to an overall agreement with each aggregated question. On the other hand, teaching method diversification in ERT had a mean of 3.3, and Difficulties in ERT had a mean of

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2.8. Those means are closer to the third element of the original Likert scale, which denotes being neutral to each question.

Continuing analysis of this first instrument block, ANOVA (or non-parametric equivalent) tests were run to compare those four scale variables considering the independent variables, as presented in Table 4.

Table 4 – Comparisons of teachers' opinions on playful learning and ERT regarding the independent variables. ANOVA or Kruskal-Wallis tests

Independent variable		Predispositions toward playful learning	Playful learning suitability in ERT	Difficulties in ERT	Teaching method diversification in ERT
Teaching experience	Test	$F_{(1,155)}$ = ,006	$F_{(1,155)}$ = .366	$F_{(1,155)}$ = .451,	$F_{(1,155)}$ = 1.46
	p	.936	.563	.503	.229
Educational level	Test	$\chi^2_{(2)}$ = 6.92	$F_{(2,154)}$ = 3.56	$F_{(2,154)}$ = 1.81,	$F_{(2,154)}$ = 1.44
	p	**.031***	**.031***	.167	.241
Institution type	Test	$\chi^2_{(3)}$ = 8.61	$F_{(3,153)}$ = 4.38	$F_{(3,153)}$ = 5.13,	$\chi^2_{(3)}$ = 5.48
	p	**.035***	**.005***	**.002***	.140

Source: Own elaboration (2022).

Kruskal-Wallis Test indicated a significant difference in teachers' predisposition toward playful learning regarding the educational level ($\chi^2_{(2)}$ = 6.92, p = .031). "*Ensino Fundamental I*" presents the highest mean rank (94.8), followed by "*Ensino Fundamental II*" (76.0) and "*Ensino Médio*" (72.3). Another Kruskal-Wallis Test also evidenced significant differences in teachers' predisposition toward playful learning considering the institution type ($\chi^2_{(3)}$ = 8.61, p = .035). "*Municipal*" schools presented the highest mean rank (93.8), followed by Private (77.1), "*Estadual*" (75.5) and "*Federal*" (63.4) schools.

An ANOVA pointed to significant differences in teachers' assertion of the Playful learning suitability in ERT according to the educational level ($F_{(2,154)}$ = 3.56, p = .031). A Bonferroni post hoc comparison was conducted to determine the differences between groups. It indicated "*Ensino fundamental I*" had a significantly higher mean, 17.2 (SD 2.80), in comparison to "*Ensino Médio*", with a mean of 15,3 (SD 3.68) (p = .001). Moreover, teachers' evaluation of the Playful learning suitability in ERT also varies according to the institution type ($F_{(3,153)}$ = 4.38, p = .005). A Bonferroni post hoc comparison clarified that "*Municipal*" schools had a mean of 16.8 (SD 2.70), significantly superior to the "*Federal*" school, with a mean of 14,44 (SD 3.70) (p = .012). Other combinations had non-significant differences.

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Teachers evaluated difficulties in ERT differently according to the institution type they work (ANOVA $F_{(3,153)}$ = 5.13, p = .002). A Bonferroni post hoc comparison test indicated that teachers' from Private and "*Federal*" schools evaluate a similar level of difficulty, with means of 38.3 (SD 11.1) and 43.3 (SD 11.2), respectively. Notwithstanding, Private schools have a significantly lower mean compared to "*Estadual*" – 45.0 (SD 10.1) (p = .042) or to "*Municipal*" Schools – mean 46.5 (SD 11.7) (p = .012). The means of "*Estadual*" and "*Municipal*" schools showed no significant difference.

Now on, we present results from the two last instrument blocks. Questions from those blocks were answered considering the period before the pandemic. Descriptive analysis shows that teacher training provided by the institution had a median of 3, which means neutral on the original Likert scale. At the same time, an autonomous search for such training presented a median of 5, which corresponds to very frequent in the original Likert scale. The use of playfulness was evaluated with a median of 4, which means frequent. Moreover, we used Kruskal-Wallis or Wilcoxon Mann-Whitney tests to compare differences in those three variables regarding the independent variables, as shown in Table 5.

Table 5 – Teacher training and Use of playful activities before the pandemic period, compared to the independent variables. Kruskal-Wallis and Wilcoxon Mann-Whitney tests

Independent variable		**Teacher training* (provided by the institution)**	**Teacher training* (autonomous search)**	**Use of playful activities**
Teaching experience	Test	Z = -.330	Z = -1.50	Z = -.160
	p	.741	.132	.873
Educational level	Test	$\chi^2_{(2)}$ = 1.66	$\chi^2_{(2)}$ = .771	$\chi^2_{(2)}$ = 23.8
	p	.436	.680	**.001***
Institution type	Test	$\chi^2_{(3)}$ = 19.5	$\chi^2_{(3)}$ = 1.961,	$\chi^2_{(3)}$ = 13.0
	p	**.001***	.581	**.005***

* Centred on teaching methods diversification.
Source: Own elaboration (2022).

Kruskal Wallis test pointed to a significant difference in teacher training provided by the institution regarding the institution type ($\chi^2_{(3)}$ = 19.5, p = .001). Private and "*Federal*" schools present the highest mean ranks, 105.8 and 94.2, respectively. By contrast, "*Municipal*" and "*Estadual*" schools resulted in smaller rank means, 69.6 and 67.0, respectively.

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The Use of playful activities frequency differs significantly regarding teachers' educational level of activity ($\chi^2_{(2)}$ = 23.8, p = .001). "*Ensino Fundamental I*" presented a much higher mean rank, 108.4, than the levels *"Ensino Fundamental II"*, 70.9; and "*Ensino Médio*", 68.2. Adiccionlly, the Use of playful activities also varies according to the institution type ($\chi^2_{(3)}$ = 13.0, p = .005). "*Municipal*" school had a mean rank of 97.5; Private school, 80.9; *"Federal"* school, 72.8; and "*Estadual*" school, 67.1.

Those same three aspects were analysed through Wilcoxon Signed Ranks tests to verify changes that might exist between the period before the pandemic and during ERT. Those results are presented in Table 6.

Table 6 – Paired comparisons of teacher training and Use of playful activities before pandemics and during ERT. Wilcoxon Signed-Ranks Test

	Teacher training* (provided by the institution)	**Teacher training* (autonomous search)**	**Use of playful activities**
Test	Z = -1,251[a]	Z = -2,276[a]	Z = -3,668[b]
p	.211	**.023***	**.001***

* Centred on teaching methods diversification.
[a] ERT > before pandemics
[b] ERT < before pandemics
Source: Own elaboration (2022).

Before the pandemic, teacher training provided by the institution had a median of three, corresponding to neutral on the Likert scale. This value did not change considering the ERT period. Differently, teacher training searched autonomously had a median of five, which corresponds to very frequent. During the ERT, this median also remained at the same value, but a Wilcoxon Signed Ranks test indicated the frequency increased significantly during the ERT (Z = -2,276 p = .023).

The Use of playful activities had a median of 4, corresponding to the frequency on the Likert scale before pandemics. During ERT, the median value changed to three, corresponding to neutral. Wilcoxon Signed Ranks test confirmed that the Use of playful activities diminished significantly between those periods (Z = -2,276 p = .023).

4 Discussions

First, we analysed the relation between predispositions toward playful learning, playful learning suitability in ERT, difficulties in ERT, and teaching method diversification

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in ERT. Results showed teachers have high levels of predispositions toward playful learning, and they evaluate it as suitable in ERT. Accordingly, this high value of teachers' predispositions to play was also found in other studies (KHALIL *et al.*, 2022). The Pearson r correlation indicated that the higher teachers' predispositions toward playful learning, the greater their evaluation of its suitability in ERT. Moreover, teachers who more intensely diversify their teaching methods in ERT also tend to positively evaluate playful learning as a suitable strategy during the ERT.

Afterwards, those same four aspects were compared regarding groups from independent variables: teaching experience, educational level and institution type. Teaching experience presented no significant differences, indicating novice and experienced teachers have similar predispositions toward playful learning, and they similarly evaluate playful learning suitability in ERT.

On the other hand, predisposition toward playful learning, evaluation of playful learning suitability in ERT, and Use of playful activities had significant differences regarding teachers' educational level and institution type. Results showed that teachers of younger children, particularly "*Ensino Fundamental I*", have a greater predisposition toward playful learning, consider it more suitable in ERT, and use it more frequently in their classes. Regarding the type of institution, teachers from "*Municipal*" schools showed a greater predisposition toward playful learning. They consider it more suitable in ERT and use it more frequently in their classes. Since "*Municipal*" schools are mainly responsible for "*Fundamental*" (BRASIL, 1996), this result represents the tendency presented in the literature that playful learning is highly valued and practised in earlier years (ALSINA, 2004; MINEIRO; D'ÁVILA, 2019; MITTON; MURRAY-ORR, 2022; SILVA, N.; SILVA, J.; COSTA, 2020). It also points out that teachers may have a restricted view of playfulness only suitable to those children instead of seeing its possibilities of applications throughout the continuum of educational levels.

Difficulties faced in ERT had significant differences only according to the institution type. Results pointed out that teachers from Private and "*Federal*" schools report fewer difficulties in this period compared to "*Municipal*" and "*Estadual*" Schools. Researchers reported that "*Municipal*" schools in Rio de Janeiro had a higher percentage of teachers who completely interrupted their activities during the pandemic period compared to the other types of schools (SANTOS; OLIVEIRA, 2021). Fonseca, Colares

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and Costa (2019) support awareness of Brazilian society on the urge to prioritise children's education in the governmental budget. Moreover, any budget manoeuvre should not diminish those resources (MENDES; MOREIRA, 2018).

Teacher training centred on teaching methods diversification also differs significantly according to the institution type. Private and "*Federal*" schools seem to provide more such teacher training than "*Municipal*" and "*Estadual*" Schools. Additionally, according to teachers' perception, the frequency of those training remained unchanged compared to before the pandemic and during ERT. Researchers report that teachers perceived they had to sort out autonomous activities during pandemics. Additionally, they felt a lack of guidance and decontrol of their institutions (SANTOS; OLIVEIRA, 2021).

Teachers indicated they frequently search for teacher training on teaching methods diversification. This autonomous search augmented significantly during the ERT. Literature states that Brazilian schools and teachers, with the pandemic, saw no way out other than, finally, reinventing, learning and embracing Information and Communication Technologies (ICT) (SOUZA, 2020).

Although results indicated difficulties in ERT are not significantly related to teachers' predispositions toward playful learning and how they evaluate its suitability in ERT, those difficulties are indeed negatively related to teaching methods diversification in this period. The use of playful activities decreased during the ERT compared to the pre-pandemic period. This result is similar to teachers from other countries, e.g., Palestinian teachers expressed that their motivation toward using playful activities decreased due to the inability to teach face-to-face during pandemics (KHALIL *et al.*, 2022).

5 Final considerations

In this study, we explored Brazilian teachers' predispositions toward playful learning bearing in mind the Emergency Remote Teaching period. We compared answers from 157 teachers according to groups of teaching experience, educational level and type of institution. Results showed an increased autonomous search for teacher education in diversifying teaching methodologies. At the same time, the formation provided by the government/institution did not accompany this augment.

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Furthermore, results showed teachers from "*Ensino Fundamental I*", and "*Municipal Schools*" have a greater predisposition toward playful learning, consider it more suitable in ERT and use it more frequently in their classes. Beyond pandemics, this configuration of "*Ensino Fundamental I*" and "*Municipal Schools*" corresponds to teaching young children. This result may be the effect of a restricted idea of playful learning being only suitable for the first educational levels.

This study has inherent limitations concerning teachers' qualitative understanding of playfulness. However, the quantitative differences presented are already potent evidence of the urge for teacher training programmes that consider those beliefs and, at the same time, reintroduce playful learning as a spectrum. Both teaching training and research about playful learning are necessary regarding its effects on older students. There should be a more nuanced understanding of play in which teachers can consider and apply it through different activities according to specific needs through the continuum of educational levels.

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Jefferson Rodrigues-Silva, Federal Institute of Minas Gerais, campus Arcos; University of Girona
[i] http://orcid.org/0000-0002-8334-2107
Professor of Mechanical Engineering and teaching. His lines of research are focused on teacher training, and STEAM Education (interdisciplinarity between Science, Technology, Engineering, Arts/Humanities and Mathematics).
Author's contribution: Conceptualization, Data curation, Formal Analysis, Investigation, Visualization, Methodology, Writing – original draft.
Lattes: http://lattes.cnpq.br/0246316357702468
E-mail: jeffe.rodri@gmail.edu.br

Ángel Alsina, University of Girona, Department of Subject-Specific Didactics
[ii] http://orcid.org/0000-0001-8506-1838
Full professor of Didactics of Mathematics. His lines of research are focused on teaching and learning mathematics at early age and training mathematics teachers.
Author's contribution: Conceptualization, Investigation, Methodology, Supervision, Validation, Writing – review & editing.
E-mail: angel.alsina@udg.edu

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D

ARTICLE D

Las matemáticas desde el abordaje STEAM en la educación primaria

Una revisión sistemática de la literatura

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LAS MATEMÁTICAS DESDE EL ABORDAJE STEAM EN LA EDUCACIÓN PRIMARIA: UNA REVISIÓN SISTEMÁTICA DE LA LITERATURA

Mathematics embedded in STEAM approach in primary education: a systematic literature review

Rodrigues-Silva, J.[a,b] y Alsina, À.[b]

[a]Instituto Federal de Minas Gerais *Campus* Arcos, [b]Universitat de Girona

Resumen

La Educación STEAM requiere la interdisciplinariedad entre Ciencia, Tecnología, Ingeniería, Artes/Humanidades y Matemáticas como estrategia para afrontar problemas complejos. Desde este punto de vista, se propone una revisión sistemática de la literatura siguiendo la Declaración de los Elementos de Información Preferidos para Revisiones Sistemáticas y Meta-Análisis (PRISMA), con el objetivo de explorar el aprendizaje de las matemáticas en los estudios empíricos sobre STEAM en la Educación Primaria. Se han revisado 19 artículos indexados en Web of Science o Scopus. Como resultado se observa que casi la mitad de los artículos no abordan el aprendizaje de las matemáticas de una manera consistente. Se concluye que existe un potencial para explicitar y desarrollar más las habilidades y conocimientos matemáticos en la educación STEAM, por supuesto, teniendo en cuenta los conocimientos que moviliza el alumnado de Educación Primaria.

Palabras clave: *matemáticas, educación STEAM, interdisciplinariedad, educación primaria.*

Abstract

STEAM Education calls for interdisciplinarity between Science, Technology, Engineering, Arts/Humanities and Mathematics as a strategy to face complex problems. From this point of view, we propose a systematic review of the literature following the Statement of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), to explore mathematics learning in empirical STEAM studies in Primary Education. We reviewed 19 articles indexed on the Web of Science or Scopus. As a result, we observed that almost half of the articles do not consistently address the learning of mathematics. In conclusion, there is a potential to further explicit and develop mathematical skills and knowledge in STEAM education, of course, taking into account the knowledge level of Primary Education students.

Keywords: *mathematics, STEAM education, interdisciplinarity, primary education.*

INTRODUCCIÓN

La educación STEAM, acrónimo del inglés que se refiere a la interdisciplinaridad entre Ciencias, Tecnologías, Ingeniería, Artes/humanidades y Matemáticas, es bastante defendida en cuanto al desarrollo de conocimientos y habilidades necesarios para que los individuos puedan afrontar la complejidad de los desafíos del siglo XXI (Fernández y Romero, 2020).

El eje de la educación STEAM consiste, pues, en la unión de las áreas que la conforman, y eso relacionado a experiencias y o contextos significativos del alumnado. Las Matemáticas suelen ser percibidas

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como omnipresentes o como un lenguaje universal entre las áreas. Si por un lado, las Matemáticas tienen una naturaleza que parece facilitar la interdisciplinaridad, por otro lado, los investigadores señalan el riesgo de perderse como área del conocimiento y tener sus objetivos de aprendizaje de conceptos y habilidades suprimidos, justificados por un sentimiento "ya garantizado" dentro de las actividades STEAM.

Considerando estas cuestiones, nos planteamos la pregunta de investigación: ¿Cómo se entiende, se practica y se investiga la enseñanza de las matemáticas desde un abordaje STEAM en la Educación Primaria? Para responder a esta pregunta, se desarrolla una revisión sistemática de la literatura con el objetivo de explorar el aprendizaje de las matemáticas en los estudios empíricos de STEAM en la Educación Primaria.

MÉTODO

Partiendo de nuestro objetivo de estudio, se ha seguido la metodología de revisión sistemática de la literatura de acuerdo con la Declaración de Elementos de Información Preferidos para Revisiones Sistemáticas y Meta-Análisis (PRISMA), donde se explica el proceso de investigación para posibilitar su reproducibilidad (Moher et al., 2015).

El proceso de investigación se ha definido en cuatro fases: 1) los elementos de búsqueda y la lógica booleana; 2) las fuentes de información; 3) los criterios de elegibilidad; 4) la extracción y el tratamiento de los datos. En los párrafos siguientes se profundiza en cada fase:

Fase 1. Elementos de búsqueda y lógica booleana

A partir del concepto clave de nuestro estudio, STEAM, y del nivel educativo que se pretende abordar, la Educación Primaria, se han formulado los elementos de búsqueda y se ha establecido la lógica booleana "*STEAM*" AND "*Primary*" OR "*Elementary*".

Fase 2. Fuentes de información

Se han elegido como fuente de información las bases de indexación *Web of Science* (WoS), de Clarivate Analytics, y *Scopus,* de Elsevier. Estas bases de datos han sido seleccionadas por su rigor y prestigio en la ciencia, y en particular por su relevancia en el campo de la investigación educativa.

Fase 3. Criterios de elegibilidad

En la tabla 1 resumimos los criterios de elegibilidad establecidos para esta revisión. Como tipo de documento, se ha establecido el criterio de inclusión de artículos de acceso abierto publicados en revistas científicas, ya que se someten a revisión por pares. El periodo de publicación abarca desde 2007, año en que se estableció el acrónimo STEAM, hasta diciembre de 2021, momento en que se realizó la búsqueda.

Tabla 1. Criterios de elegibilidad.

Criterios	Inclusión	Exclusión
Tipo de documento	Artículo	No artículos
Acceso a los documentos	Acceso abierto	Acceso restringido
Periodo de publicación	2007 - 2021	2006 o antes
Área de investigación	Educación	No educativo

Idioma	Inglés o español	Otros idiomas
Diseño de la investigación	Empírico	Teórico
Población estudiada	Práctica con estudiantes	No centrado en los estudiantes
Enfoque pedagógico	STEAM	Otros enfoques

Otro criterio ha sido incluir sólo los estudios registrados en el área de investigación educativa, de acuerdo con nuestro interés de investigación, evitando STEAM referente a "vapor". Además, respecto al idioma, se han seleccionado los documentos escritos en inglés, porque los artículos se publican mayoritariamente en este idioma; y en español, para incluir trabajos de países hispanohablantes.

Los tres últimos criterios se han establecido para refinar la selección de documentos a través de la lectura de los títulos y resúmenes de los artículos. Sólo se han incluído estudios empíricos, centrados en los estudiantes y que citasen explícitamente la Educación STEAM. Luego, con la lectura integral de los documentos, se ha verificado si todos los criterios elegibilidad se cumplían para garantizar que los estudios realmente estuviesen alineados con el objetivo de la investigación.

Los criterios de exclusión han sido básicamente antónimos a los de inclusión. Es decir, documentos que no sean artículos o de acceso restringido. También, documentos publicados antes de 2006, en ámbitos no educativos, escritos en idiomas distintos al inglés o al español. Por último, se ha adoptado el criterio de excluir los estudios teóricos y no centrados en el alumno, o centrados en enfoques educativos distintos de STEAM.

Fase 4. Extracción y tratamiento de datos

La lógica booleana establecida ha sido usada para escaneos en los títulos, resúmenes y palabras clave de los documentos. Encontramos inicialmente 12378 documentos localizados en *Web of Science* y *Scopus*. A continuación, se han usado los filtros de las plataformas para aplicación de los criterios de elegibilidad, como se muestra en la parte izquierda de la figura 1. De esta forma, se llega a 116 documentos.

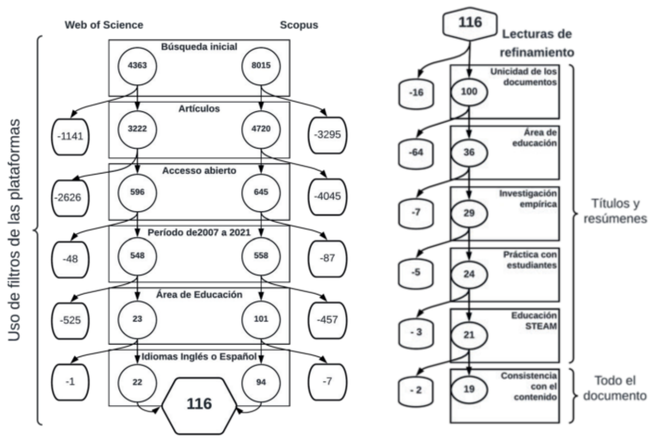

Figura 1. Filtrado mediante los motores de búsqueda de las plataformas *Web of Science* y *Scopus* y posteriores lecturas de refinamiento.

Como se puede apreciar en la parte derecha de la figura 1, a partir de los 116 artículos se ha realizado un refinamiento con la lectura de títulos y resúmenes. A partir de la unicidad de los documentos (excluyendo los repetidos), se han mantenido aquellos del ámbito educativo, con diseños empíricos, centrados en los estudiantes y que citen explícitamente la Educación STEAM. Seguidamente se ha realizado la lectura integral de los textos. En este proceso se han excluído dos artículos más, el estudio de Sengupta-Irving y Vossoughi (2019), porque no se trata de Educación Primaria, y el estudio de Bureekhampun y Mungmee (2020) porque se centra en el diseño de robots y la participación de los estudiantes se aborda de forma periférica.

Por lo tanto, culminamos con una lista de 19 artículos para esta revisión de literatura. Estos artículos han sido analizados mediante una primera lectura para conocimiento general de los textos; una segunda lectura para establecimiento de categorías de análisis; y lecturas posteriores para revaluación de las categorías y hasta la saturación del análisis.

RESULTADOS

Los resultados se presentan en dos partes: primero, se describen los artículos seleccionados en la revisión a partir de informaciones generales (zona geográfica del estudio, muestra, diseño metodológico etc.); seguidamente, se sitúa el foco en el aprendizaje de las matemáticas explicitado en algunos trabajos, seguido de una descripción sucinta de las prácticas pedagógicas desarrolladas.

Empezamos, pues, presentando informaciones generales de los estudios revisados en la tabla 1. En ella, podemos observar el listado de artículos, país, muestra, diseño metodológico, instrumento de recogida de datos, análisis y método de enseñanza. Se observa que los artículos se concentran temporalmente en los años más recientes, uno publicado en 2019, diez en 2020 y ocho en 2021. La distribución geográfica es heterogénea: gran parte de estudios han sido desarrollados en España (7), seguido por Finlandia (4), Corea (3) y China (2). Mientras Chile, Indonesia, Malasia aportan a esta revisión con apenas un estudio cada uno.

Metodológicamente, se observan estudios con muestras muy pequeñas, de 8 participantes, hasta muestras más amplias de 790 participantes. Sobre el diseño metodológico, casi la mitad de los artículos consisten en estudios de caso (9). Los otros pueden ser clasificados como cuasi-experimental (5) o experimental (5). El instrumento de recogida de datos preferido entre los autores es, sin duda, el cuestionario (10), seguido de vídeo (6) y notas de campo (6). Algunos trabajos usan más instrumentos asociados. El análisis de contenido es la estrategia de análisis más frecuente (8), seguida de estadística con tests paramétricos (7).

Las metodologías de enseñanza empleadas se concentran en el aprendizaje basado en proyectos (10), seguido de Aprendizaje Basado en Problemas (3). El juego, el aprendizaje experimental o artístico y la robótica están frecuentes respectivamente en dos estudios.

Ocho trabajos no abordan de manera consistente el papel o el aprendizaje de las matemáticas en sus planteamientos o resultados. Un mismo grupo de autores, por ejemplo, hizo grabaciones del alumnado mientras desarrollaban retos STEAM, focalizándose en el comportamiento y diálogo de los alumnos (Kajamaa y Kumpulainen, 2020), satisfacción (Kumpulainen y Kajamaa, 2020) y constructos de liderazgo (Leskinen et al., 2021). Aunque aparecieron situaciones como el ajuste de ángulos de un rayo láser, estas no fueron abordadas en profundidad. Cabello et al. (2021), por ejemplo, reportan que ellos tuvieron dificultad en la integración de contenidos o habilidades matemáticas en las actividades.

Por otro lado, 11 artículos han abordado las Matemáticas. Estos estudios se muestran en la tabla 2, con la descripción de la actividad pedagógica desarrollada. De estos artículos, se observa que muchos proponen actividades pedagógicas relacionadas a la electricidad, como la construcción de una casa en miniatura con un generador eléctrico (Adriyawati et al., 2020), el diseño de iluminación de una habitación (Greca et al., 2021) o la creación de una iluminación con imágenes cortadas en papel (Lu et al., 2021).

Algunas descripciones de los aprendizajes matemáticos consisten en mediciones de tiempo, longitud (como en Adriyawati et al., 2020; Bassachs et al., 2020; Lu et al., 2021), comprensión o clasificación del movimiento (Bassachs et al., 2020; Tan et al., 2020). Algunos explicitaron aspectos relacionados a formas geométricas (Espigares-Gámez et al., 2020; Fernández-Oliveras et al., 2021; Song et al., 2019).

Tabla 2. Lista de artículos con información sobre el país, muestra, el diseño metodológico, instrumentos de recogida y análisis de datos de los estudios.

Artículo	País	Muestra	Diseño metodológico			Instrumento de recogida de datos							Análisis					Método de enseñanza				
			Estudio de caso	Cuasi-experimental	Experimental	Entrevista	Narración reflexiva	Cuestionario	Grabaciones de Video	Producto final	Notas de campo	Análisis de contenido	Interacción multimodal	Estad. paramétrica	Estad. no paramétrica	Estad. descriptiva	Proyecto	Juego	Experimental/artística	Problemas	Robótica
Adriyawati et al. (2020)	Indonesia	30	x			x	x			x	x	x					x				
Bassachs et al. (2020)	España	90			x	x					x	x			x				x		
Cabello et al. (2021)	Chile	95	x				x	x			x	x		x					x		
Fernández y Romero (2020)	España	57		x				x		x				x							x
Cervera et al. (2020)	España	24		x				x								x					x
Espigares-Gámez et al. (2020)	España	16	x						x		x	x						x			
Fernández-Oliveras et al. (2021)	España	32	x						x		x	x						x			
Greca et al. (2021)	España	121	x				x				x	x								x	
Jang et al. (2020)	Corea	58			x			x						x						x	
Kajamaa y Kumpulainen (2020)	Finlandia	8	x						x				x				x				
Kumpulainen y Kajamaa (2020)	Finlandia	94	x						x				x				x				
Kwack y Jang (2021)	Corea	270			x			x						x						x	
Leskinen et al. (2021)	Finlandia	20	x						x				x				x				
Lu et al. (2021)	China	21		x				x	x	x		x					x				
Song et al. (2019)	Corea	790			x	x		x						x			x				
Tan et al. (2020)	Malasia	59		x				x						x			x				
Tran et al. (2021)	China	66			x			x						x			x				
Ruiz Vicente et al. (2020)	España	30		x				x								x	x				
Yliverronen et al. (2021)	Finlandia	19	x						x			x					x				

Tabla 2. Descripción de la actividad pedagógica y el abordaje de las matemáticas en los estudios.

Artículo	Descripción de la actividad pedagógica	Abordaje de las Matemáticas
Adriyawati et al. (2020)	Construcción de una casa en miniatura con un generador eléctrico de fuente manual o solar	Cálculos de tiempo en la fabricación de herramientas, conceptos matemáticos para encontrar el tamaño (medición) adecuado para cada campo requerido
Bassachs et al. (2020)	Experimentos científicos y traslación de conceptos físicos al movimiento-danza	Medidas de longitud y tiempo, clasificación de movimiento
Cabello et al. (2021).	Retos con distintos problemas de investigación	Recopilar, analizar y representar datos matemáticamente
Fernández y Romero (2020)	Programación y construcción de los robots	Pensamiento computacional, descomposición, abstracción, iteración y generalización
Espigares-Gámez et al. (2020)	Juegos tradicionales jamaicanos	Enfoque etnomatemático: matemáticas cotidianas interculturales en juegos. Identificación de formas, figuras planas, rotaciones, relaciones topológicas espaciales, longitudes o distancias vacías, ángulos en trayectorias hipotéticas, elaboración y percepción de estructuras espaciales
Fernández-Oliveras et al. (2021)	Juegos tradicionales	Enfoque etnomatemático: Identificar formas planas y cuerpos tridimensionales, situarse en el plano y el espacio, ordenar, clasificar, reconocer patrones, mensurar y aproximar. Plantear cuestiones numéricas y determinar aspectos geométricos
Greca et al. (2021)	Diseño de iluminación de una habitación	Recoger, clasificar, representar e interpretar datos obtenidos sobre el consumo de electricidad
Lu et al. (2021)	Luminaria con imágenes cortadas en papel: programación lógica con conexión de sensores, luces, altavoz	Medición simple, cálculo del tiempo, álgebra, pensamiento lógico, función.
Song et al. (2019)	Programación de pantalla flexible de LED	Identificación de distintas formas geométricas y creación de patrones
Tan et al. (2020)	Diseño de juegos e historias animadas centrado en conceptos sobre electricidad	Calcular y modificar los pasos de los personajes
Tran et al. (2021)	Diseño de un cofre en forma de casa	Principios matemáticos de la cerradura (explicación no profundizada), identificar y separar monedas

En contrapartida, hay trabajos que exploran el uso de las matemáticas de manera más profunda, como asociado al proceso investigativo, en la recogida, análisis y representación de dados (Cabello et al., 2021; Greca et al., 2021), o bien relacionado con la programación y el pensamiento computacional, por la descomposición, abstracción, iteración y generalización. Espigares-Gámez et al. (2020) y Fernández-Oliveras et al. (2021) explotan el carácter etnomatemático en el uso de juegos tradicionales. Explicitan una serie de procesos cognitivos matemáticos, como identificar formas planas y cuerpos tridimensionales, situarse en el plano y el espacio, ordenar, clasificar, reconocer patrones, mensurar y aproximar.

CONCLUSIONES

Las investigaciones empíricas de STEAM en Educación Primaria de esta revisión han sido, en su gran mayoría, publicadas en 2020 o 2021, y concentradas en España. En estos estudios, se desarrollan metodologías de aprendizaje activas, especialmente el Aprendizaje Basado en Proyectos (ABP). Casi la mitad de los artículos no abordan el aprendizaje de las Matemáticas de una manera mínimamente consistente. Entre los que sí lo trabajan, algunos se restringen a usos más sencillos, como mediciones de tiempo y de longitud. Mientras otros trabajan las matemáticas de manera más profunda e interdisciplinar, como asociado al proceso investigativo: en la recogida, análisis y representación de dados. También trabajan las Matemáticas desde el contexto cotidiano intercultural, como en la perspectiva de la Eetnomatemática. La revisión bibliográfica puede ser útil para informar la agenda de investigación en torno a las matemáticas en STEAM. Se concluye que existe un potencial, pero aún poco explotado, de argumentación matemática en el marco de las conexiones interdisciplinares (Alsina et al., 2021) y de desarrollo de las habilidades y conocimientos matemáticos en la educación STEAM, por supuesto, teniendo en cuenta el nivel del alumnado en Educación Primaria. En el futuro se pretende expandir la revisión añadiendo con nuevos trabajos y con publicaciones de revistas con acceso restringido.

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