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Gender Equity in STEAM Education: Evidence from Lower Secondary Students in Portugal

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Abstract

Equity in science education remains a pressing global challenge, as persistent gender disparities continue to shape students' participation, motivation, and career aspirations in STEM fields. This study examines whether a curriculum-integrated STEAM (Science, Technology, Engineering, Arts and Mathematics) subject, implemented in a Portuguese private school with 82 lower secondary students (seventh and eighth grade), is associated with equitable engagement among boys and girls. A mixed-methods design was adopted, combining Likert-scale questionnaires with classroom observations. While qualitative data provided contextual insight into students' overall participation and engagement in hands-on and creative activities, gender-related comparisons were based exclusively on quantitative questionnaire responses. Inferential analyses revealed no significant differences between boys and girls in their perceptions of the STEAM subject, their engagement with the activities, or their perceived skill development. These findings suggest that the design of practical, student-centred STEAM experiences may support comparable participation and engagement among involvement of both boys and girls. The results highlight the importance of curriculum design and pedagogical approaches as key factors in promoting more inclusive science education, with implications for policy and practice aimed at engaging all learners in science.

Keywords: STEAM education; gender equity; science education; interdisciplinary teaching; lower secondary

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Academic Editors: Laurinda Leite and Luís Dourado

Received: 29 May 2026
Revised: 21 June 2026
Accepted: 26 June 2026
Published: 28 June 2026

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1. Introduction

In recent decades, education systems have undergone profound transformations driven by globalisation, rapid technological development, and the emergence of a knowledge-based economy. These challenges have emphasised the limitations of pedagogical models predominantly centred on memorisation and the reproduction of information, reinforcing the need for approaches that promote higher-order cognitive skills, such as critical thinking, creativity, complex problem-solving, and collaboration. According to the World Economic Forum, these skills are central pillars of contemporary education, preparing citizens for active, critical, and innovative participation in democratic and technologically advanced societies (WEF, 2020b).

In this context, STEM education—an acronym for Science, Technology, Engineering, and Mathematics—has become internationally established as a response to the need to

bring school learning closer to contemporary scientific, technological, and social challenges. Initially associated by the National Science Foundation with four distinct disciplinary areas—Science, Technology, Engineering, and Mathematics—STEM education has acquired different meanings in the literature. The absence of a consensual definition has been widely noted, with different understandings regarding its conceptual boundaries, the professional fields it encompasses, and the degree of pedagogical integration among the disciplines involved (Dare et al., 2019; Mildenhall et al., 2019; Van den Hurk et al., 2018). As Bybee (2013) observes, although many authors seek a clear definition of STEM education, its meaning remains ambiguous: in some cases, STEM is understood as the simple juxtaposition of four separate disciplines; in others, as an integrated approach that brings together knowledge, practices, and skills around shared problems.

This conceptual diversity has direct implications for the way STEM is put into practice in educational contexts. For some authors, STEM teaching involves the articulation of two or more disciplines with a focus on practices, skills, and problem-solving, with Engineering playing a particularly relevant, though not exclusive, role as an integrating field (Timms et al., 2018). Other authors emphasise that STEM may be understood either as a single field or as a multidisciplinary approach, although there is not always clarity regarding its pedagogical integration. Within this framework, Science and Mathematics often appear as more consolidated areas within the curriculum, whereas Engineering and Technology tend to be taught in more specific or less systematic contexts (Holmlund et al., 2018). Nevertheless, the STEM designation is justified by the interconnection between disciplines that share common themes, problems, and practices, allowing complex phenomena to be explored from multiple perspectives (Park et al., 2020).

The evolution from STEM to STEAM, through the inclusion of the Arts, has broadened the educational potential of this approach. The integration of the artistic dimension has enhanced the value of imagination, design, experimentation, and creative expression as essential components of scientific and technological thinking. Historically recognised as a driving force of scientific progress (Einstein & Infeld, 1938), creativity assumes a structuring role in this context, enabling students to explore multiple solutions, test hypotheses, establish connections between areas of knowledge, and construct meaningfully grounded understanding (Bequette & Bequette, 2012; Turkka et al., 2017). Thus, STEAM proposes an interdisciplinary integration of scientific and technological knowledge with creative and expressive processes, bringing learning closer to authentic and socially relevant situations (LaForce et al., 2016; Sjøberg, 2015).

One of the earliest theoretical approaches associated with STEAM education was proposed by Yakman (2007), through a model in which the disciplines are articulated in an integrated way. From this perspective, the understanding of science can be mediated by Technology, while Art plays an essential role in attributing meaning, depth, and creativity to knowledge. In this model, Mathematics functions as a connecting element between the different areas, helping to structure reasoning and support the understanding of the phenomena under study. Yakman further argues that STEAM has an adaptable nature from economic, social, and educational perspectives, promoting multidisciplinary practices capable of preparing more informed, creative, and functional citizens to face contemporary challenges.

From a pedagogical point of view, STEAM is particularly well aligned with active methodologies, such as project-based learning and problem-based learning. These methodologies place students at the centre of the educational process, promoting autonomy, decision-making, collaborative work, and active engagement with real-world challenges (Barron et al., 1998; Yew & Goh, 2016). Rather than encouraging a fragmented approach to learning, STEAM encourages the integrated mobilisation of knowledge, skills, and at-

titudes, allowing students to understand the social relevance of what they learn and to develop creative responses to complex problems.

Beyond its cognitive and procedural benefits, STEAM has increasingly been recognised for its inclusive and popularising potential. Research in science education has consistently documented the persistence of gender inequalities in STEM fields, reflected in students' motivation, engagement, academic and professional choices. Despite significant progress in access to higher education, girls remain underrepresented in domains such as Engineering, Physics, and Information Technologies (LaForce et al., 2016; WEF, 2020b; National Academies of Sciences, Engineering, and Medicine, 2020). OECD data confirm that, although women constitute a growing proportion of graduates, their presence remains uneven across scientific fields, revealing persistent patterns of horizontal and vertical segregation (OECD, 2018, 2019).

The literature has identified multiple explanatory factors for these disparities, including cultural gender stereotypes, differentiated social expectations, and lower levels of self-confidence among girls regarding their mathematical and scientific competencies (Blickenstaff, 2005; Ikkatai et al., 2019). These factors influence the early construction of academic and vocational identities, shaping interests, curricular choices, and future professional pathways.

Within this framework, schools play a decisive role. Evidence suggests that traditional pedagogical practices, centred on oral exposition and disciplinary fragmentation, may contribute to a decline in students' interest and engagement, particularly among girls (Holmegaard et al., 2014; Barmby et al., 2008). By contrast, active, collaborative, and contextualised approaches, characteristic of STEAM education, have shown greater capacity to stimulate motivation, strengthen perceived competence, and promote more inclusive learning experiences (Henriksen et al., 2015; Rainey et al., 2019). By integrating science, technology, and creativity into practical and socially relevant tasks, STEAM can reduce symbolic barriers associated with scientific and technological fields, broadening the sense of belonging among students with different profiles.

In Portugal, this discussion is particularly relevant. The curricular guidelines expressed in the *Students' Profile by the End of Compulsory Schooling* booklet, emphasise competencies such as critical thinking, autonomy, creativity, aesthetic and artistic sensitivity, scientific reasoning, and problem-solving—dimensions directly aligned with the principles of STEAM (DGE, 2017). Despite relatively positive indicators of female participation in higher education in science, significant asymmetries persist in areas such as Engineering and Information Technologies (OECD, 2018), suggesting the need for early pedagogical interventions that promote more equitable experiences in basic education.

Thus, the STEAM approach emerges as a promising pedagogical pathway for responding simultaneously to the educational demands of the twenty-first century and to the challenges of equity in education. By combining scientific rigour, technological thinking, mathematical reasoning, engineering practices, and artistic creativity, this approach enables meaningful, interdisciplinary, and inclusive learning, contributing to the development of students who are capable of understanding, questioning, and transforming the world around them.

Although the international literature recognises the potential of STEAM to increase student engagement and contribute to the reduction in inequalities, empirical studies examining, in real school contexts, how the systematic curricular implementation of STEAM subjects may influence the perceptions and experiences of boys and girls remain scarce. This gap is particularly relevant in the Portuguese context, where the relationship between sustained STEAM approaches and gender-related educational experiences with potential implications for educational equity at the lower secondary level remains underexplored.

It is within this framework that the present study is situated. Its aim is to analyse the extent to which the implementation of a STEAM subject in lower secondary education is associated with similar levels of motivation, engagement, and perceived learning among boys and girls. By exploring students' experiences in an active and interdisciplinary teaching context, the study seeks to understand the potential of these pedagogical practices to create more inclusive and equitable learning environments, contributing to reflection on educational strategies capable of broadening the participation of all students in scientific and technological fields.

2. Literature Review

Gender inequality in STEM remains one of the most persistent challenges identified by research in science education. Despite progress in access to higher education, significant disparities persist in motivation, interest, self-confidence, and female representation in academic and professional pathways related to science and technology (LaForce et al., 2016; WEF, 2020b; OECD, 2018, 2019). These inequalities are not limited to the numerical presence of girls and women in these fields; they are also reflected in students' sense of belonging, career expectations, and the construction of academic and vocational identities from an early age.

The literature has shown that these disparities result from a combination of individual, social, and contextual factors. Among these, gender stereotypes, differentiated social expectations, the lower visibility of female role models in scientific and technological fields, and lower levels of self-efficacy among girls regarding their mathematical and scientific competencies stand out (Blickenstaff, 2005; Ikkatai et al., 2019). Even when their academic performance is similar to that of boys, many girls tend to show lower confidence in their abilities and a stronger perception that "special skills" are required to pursue STEM studies or careers (Merayo & Ayuso, 2022). This discrepancy suggests that barriers to female participation are not only structural but also psychological and symbolic.

Recent studies confirm the persistence of these differences in interest. Merayo and Ayuso (2022), in a study with Spanish secondary school students, identified a gap of around 14% in interest in STEM pathways between boys and girls. Beyond the size of this difference, the authors highlight distinct motivations: while girls tend to place greater value on the social impact and collective usefulness of professions, boys attribute greater importance to financial rewards and career opportunities. These orientations reflect internalised social expectations and gender roles, which influence how students perceive scientific and technological fields.

Qualitative research reinforces this interpretation. Verdugo-Castro et al. (2023) show that stereotypical associations between masculinity, leadership, and technical competence continue to persist, while girls tend to identify more frequently with roles related to care, support, or mediation. These social narratives shape identification with scientific and technological careers. The absence of visible female role models further aggravates this situation: according to Microsoft (2017), many young European women report difficulty in naming female references in STEM fields, which may contribute to the perception that these domains do not belong to them.

In addition to individual and sociocultural factors, the composition of learning contexts also appears to influence students' academic performance and engagement. Bowman et al. (2022), in a study involving almost 12,000 university students enrolled in STEM courses, showed that environments with greater female representation are associated with better overall academic outcomes, with particular benefits for female students. This effect was even more pronounced when classes were taught by female instructors, underlining the

role of representation, pedagogical climate, and identification with positive role models in promoting more equitable educational experiences.

Consistently, Hasenhütl et al. (2024) found that interventions centred on gender-sensitive pedagogical practices lead to similar levels of enthusiasm, satisfaction, and engagement among boys and girls. These findings suggest that inclusive environments not only benefit traditionally underrepresented groups but also contribute to improving the quality of learning for all students. Thus, gender equity should be understood not only as a matter of social justice but also as a relevant dimension of educational effectiveness.

Although the terms gender equality and gender equity are often used interchangeably, they refer to related but distinct concepts. Gender equality generally refers to the absence of differences in rights, opportunities, participation, or outcomes between boys and girls. Gender equity, in contrast, emphasises fairness in the provision of educational opportunities and resources, recognising that different groups may require different forms of support in order to achieve comparable educational experiences and outcomes.

Within science and STEM education, equity therefore extends beyond the simple absence of observable gender differences. It also encompasses broader dimensions such as participation, belonging, self-efficacy, identity development, and access to meaningful learning opportunities. Consequently, evidence of similar perceptions or outcomes between boys and girls may be consistent with equitable educational experiences, but does not by itself constitute definitive evidence of gender equity.

Against this background, recent research has increasingly focused on evaluating educational interventions capable of reducing gender disparities in STEM. Converging findings indicate that practical, collaborative, contextualised, and socially relevant learning experiences can increase girls' engagement, self-confidence, and interest in scientific and technological fields. Lynch et al. (2024), for example, demonstrated that workshops combining experimental activities with the presentation of female scientists significantly increased female students' identification with Physics and their ability to imagine themselves in scientific careers. Similarly, Ribeirinha et al. (2024) found that inquiry-based approaches contributed to reducing gender differences in interest in STEM careers.

These conclusions are aligned with the broader literature on active methodologies, such as project-based learning and problem-based learning, which show consistent gains in motivation, critical thinking, collaboration, and sense of belonging (Barron et al., 1998; Yew & Goh, 2016). By bringing science closer to real-world contexts, promoting students' active participation, and valuing multiple forms of competence, these approaches appear to counteract the demotivating effects of traditional pedagogies centred on oral exposition, disciplinary fragmentation, and memorisation (Holmegaard et al., 2014; Barmby et al., 2008).

At the same time, research highlights the role of teacher representation and identification models. Xie et al. (2021) show that the presence of female teachers in informal learning contexts is associated with greater interest among girls in Mathematics and Science, reinforcing the importance of positive female role models from an early age. This dimension is particularly relevant in areas where female representation remains limited, since the visibility of women in scientific and technological roles can help challenge stereotypes and broaden girls' possibilities for identification.

More recently, the literature has emphasised that gender inequality does not operate in isolation. Socioeconomic, cultural, and school-related factors interact with gender, producing differentiated experiences of access, confidence, and participation. Studies involving young people from socioeconomically disadvantaged backgrounds indicate lower levels of interest and self-efficacy regarding science, suggesting that barriers to participation may be cumulative (Boyle et al., 2023). This intersectional perspective reinforces the need for edu-

cational interventions that are sensitive to the diversity of students' contexts, trajectories, and experiences.

Taken together, recent empirical evidence points to two central aspects. On the one hand, gender disparities in STEM persist consistently across different countries, disciplinary areas, and educational levels. On the other hand, these differences are not inevitable: inclusive pedagogical environments, practical and collaborative methodologies, the visibility of female role models, and gender-sensitive approaches show potential to reduce inequalities and promote greater engagement among all students (Bowman et al., 2022; Hasenhütl et al., 2024; Lynch et al., 2024; Ribeirinha et al., 2024; Xie et al., 2021).

Despite growing evidence regarding the positive impact of short-term or one-off educational interventions, less is known about the effect of STEAM subjects that are systematically integrated into the curriculum, especially at intermediate levels of schooling and in real school contexts. This gap is particularly relevant in the Portuguese context, where studies analysing the year-long implementation of a STEAM subject in lower secondary education, and how it relates to the learning experiences of boys and girls, remain scarce.

Thus, the present study seeks to answer the following research question: Are there significant differences between boys and girls in terms of motivation, engagement, and perceived learning in a STEAM subject integrated into the lower secondary curriculum?

3. Materials and Methods

3.1. Research Design

The present study adopted a mixed-methods case study design, combining qualitative and quantitative approaches, aimed at an in-depth analysis of the implementation of a STEAM subject in a real school context. This methodological choice was considered appropriate for investigating complex and situated pedagogical practices, as it allows for an understanding of processes, classroom dynamics, and students' experiences within their natural learning environments, rather than isolating variables under artificial experimental conditions (Cohen et al., 2007; Thomas, 2013; Yin, 2009, 2018).

A mixed-methods strategy with convergent triangulation was followed (Creswell, 2009; Johnson et al., 2007), combining quantitative data analysis obtained through a questionnaire with qualitative data collected through classroom observation. Both datasets were gathered during the same time period, over the course of a full academic year, and were analysed in a complementary manner, with the aim of cross-referencing students' self-reported perceptions with observational evidence regarding their engagement, participation, and interaction in the proposed activities. The qualitative component was not designed to provide a systematic comparison between boys and girls. Rather, classroom observations were used to document students' overall experiences, participation, engagement, and interaction during the implementation of the STEAM subject, thereby providing contextual evidence to complement the quantitative findings.

The study follows a single post-test design, since the quantitative data were collected at the end of the academic year, with no pre-test administered and no control group established. This choice resulted from the specific and real conditions under which the research was implemented. Although students had already attended a STEAM subject previously, the activities and classroom dynamics implemented during the present study were entirely new and therefore not comparable to those experienced in previous years. Consequently, they lacked a specific, directly related baseline measure that would have allowed for a traditional pre-test assessment regarding this new set of experiences. Furthermore, for organisational reasons and due to the school's educational policy, the subject was offered to all participating classes, making it neither pedagogically nor institutionally appropriate to exclude some students from attending it solely for the purpose of creating a control group.

In this sense, the study does not seek to establish causal relationships between attendance in the STEAM subjects and the observed outcomes. Rather, it aims to understand, in a natural context, how a STEAM subject integrated into the curriculum is associated with indicators of motivation, engagement, and perceived learning.

The pedagogical intervention consisted of the continuous implementation of a STEAM subject integration into the lower secondary school curriculum, with weekly 60 min sessions throughout the entire academic year. All classes were taught by the same teacher, ensuring consistency in planning, teaching strategies, criteria for conducting activities, and the way students were supported, thereby reducing variability associated with different teaching styles.

The combination of prolonged observation in a natural context, systematic collection of students' perceptions, and triangulation between methods sought to strengthen the ecological validity of the study. Ecological validity is understood here as the proximity between the research conditions and the real conditions in which educational practice takes place; that is, the possibility of analysing the subject as it was actually taught, with the constraints, interactions, rhythms, and dynamics characteristic of a real classroom. Thus, the study prioritised a contextualised understanding of how the subject functioned over controlled experimental inference.

Accordingly, the central aim was to describe and interpret the extent to which students' experience in a curricular STEAM subject, implemented over the course of an academic year, was associated with indicators of motivation, engagement, and perceived learning among boys and girls, thereby contributing to an understanding of the potential of these approaches in authentic school contexts.

3.2. Sample and Context

The study was conducted in a private school in the district of Aveiro, Portugal, where a STEAM subject was integrated into the complementary curricular provision of lower secondary education. The selected context made it possible to follow the systematic and sustained implementation of a STEAM subject throughout the entire academic year, providing a valuable opportunity to observe authentic pedagogical practices under real classroom conditions. In addition, the fact that the sample came from a relatively homogeneous and generally advantaged socioeconomic school context made it possible to reduce variability associated with socioeconomic differences among participants. This characteristic enabled an analysis more focused on differences between boys and girls, although the results should be interpreted in light of the specificity of the context and the consequent limitations regarding their generalisation to more diverse school populations.

The sample comprised all students enrolled in the seventh- and eighth-grade classes who attended the subject during the academic year under analysis, totalling 82 students. The gender distribution was relatively balanced, with 46 boys (56.1%) and 36 girls (43.9%), allowing comparisons between groups of similar size.

The sample is a convenience sample, drawn from a very specific educational context in Portugal in which a STEAM subject was included in the study plan. Although this choice limits the statistical generalisability of the results, it is consistent with the logic of a case study, which privileges the in-depth analysis of specific contexts and the detailed understanding of situated pedagogical processes (Yin, 2018).

All classes were taught by the same teacher throughout the academic year, ensuring consistency in curricular planning, teaching strategies, and the implementation of STEAM activities. This homogeneity reduces variability associated with different teaching styles, reinforcing the internal coherence of the case under study, although it limits comparison with other pedagogical approaches.

3.3. Instruments

3.3.1. Questionnaire

Quantitative data were collected through a structured questionnaire administered at the end of the academic year, designed to gather students' perceptions of their experience in the STEAM subject. The instrument aimed to characterise dimensions such as motivation, engagement, perceived learning, autonomy, creativity, and the use of technologies, as well as to compare these perceptions between boys and girls.

The questionnaire comprised 23 statements organised into thematic groups, answered using an even six-point Likert scale. The choice of a scale without a neutral midpoint was intended to encourage participants to take a position and to reduce ambivalent or indecisive responses, a strategy considered appropriate in educational contexts when the aim is to capture attitudes and perceptions in a more differentiated way (Simms et al., 2019).

The questionnaire was designed to analyse different aspects of students' experience in the STEAM subject, rather than to produce a single global score. Thus, the statements included in the instrument were not treated as if they all measured the same dimension, but rather as indicators of specific aspects, such as motivation, engagement, perceived learning, autonomy, creativity, and the use of technologies. This choice made it possible to analyse each item separately, in a way that was more appropriate to the exploratory nature of the study and to the aim of understanding how students perceived the subject in a real context. Nevertheless, Cronbach's alpha was calculated as a complementary analysis, with the purpose of examining the overall coherence of responses to the questionnaire (Briggs & Cheek, 1986). Given the multidimensional nature of the instrument, the coefficient was used only as a descriptive indicator of the overall consistency of responses and not as evidence that the questionnaire measured a single underlying construct. A high reliability coefficient was obtained ($\alpha = 0.947$), indicating excellent internal consistency and suggesting that, despite the thematic diversity of the items, students' responses showed an overall stable pattern of perceptions regarding their experience in the STEAM subject. This result was therefore interpreted as reflecting the overall coherence of responses across the questionnaire rather than the existence of a single underlying dimension, since the instrument was designed as a set of indicators addressing different aspects of students' experience.

Accordingly, each statement was treated as a specific indicator of one facet of students' experience, allowing distinct dimensions to be analysed separately. This approach is consistent with the exploratory nature of the case study, whose purpose is to describe patterns of perception in a real context rather than to produce generalisable psychometric measures.

Content validity was ensured through a review process involving four experts in science education and STEAM methodologies, who assessed the clarity, relevance, and suitability of the statements in relation to the aims of the study. Face validity was verified through the prior administration of the questionnaire to a group of students of similar age and school context to the participants, making it possible to confirm the comprehensibility of the items and the appropriateness of the language used.

As the participants were minors, students' assent and the informed consent of their legal guardians were obtained before the beginning of the study. The questionnaire was administered online during class time, ensuring similar administration conditions for all participants. Participation was anonymous and voluntary, with the aim of minimising potential effects of social desirability or assessment-related pressure. The confidentiality of the data collected was guaranteed, and their processing and storage complied with the ethical principles applicable to research with minors, as well as with national and European legislation on the protection of personal data.

In the data analysis, a predominantly descriptive and item-by-item strategy was adopted, complemented by thematic groupings used for organisational purposes. Mea-

sures of central tendency and dispersion were reported, namely mean and standard deviation, as well as gender comparisons using non-parametric tests suitable for independent samples and non-normal distributions. This approach made it possible to obtain a detailed characterisation of students' perceptions, aligned with the exploratory aims of the study, while also preserving methodological transparency regarding the limitations inherent to self-report instruments.

3.3.2. Classroom Observation and Field Notes

The qualitative component of the study was based on participant observation throughout the entire academic year, continuously following the development of activities in the STEAM subject. This strategy made it possible to collect detailed contextual information on students' participation, interaction, and engagement processes.

The observations were recorded as descriptive field notes, written regularly by the teacher–researcher after classes. These records included descriptions of observable behaviours, group dynamics, problem-solving strategies, levels of participation, reactions to the proposed tasks, and episodes considered representative of students' cognitive and collaborative engagement. Particular attention was given to indicators such as initiative, autonomy, peer communication, persistence in the face of difficulties, and ways of appropriating scientific concepts.

An open and narrative record was chosen instead of a rigid categorical grid, in order to capture the complexity and diversity of classroom interactions, a feature often valued in educational case studies (Thomas, 2013; Yin, 2018). This approach made it possible to document unexpected events, emerging behaviours, and contextual nuances that would be difficult to capture through structured instruments.

In addition, the field notes were reviewed periodically and analysed iteratively, with the aim of identifying recurring patterns across sessions. Emerging categories were refined through successive readings and the comparison of similar episodes, promoting greater analytical consistency. This systematic procedure sought to strengthen the credibility and interpretive robustness of the inferences drawn from the observations.

It is also acknowledged that the dual role of teacher and researcher may introduce potential interpretive biases, particularly because of the researcher's proximity to the observed context. To mitigate this risk, the records prioritised factual descriptions of concrete situations, avoiding immediate evaluative judgements and relying, whenever possible, on observable examples of behaviours and interactions. Moreover, the purpose of the field notes was not to produce independent generalisations, but to complement and contextualise the quantitative data within a logic of methodological triangulation.

Thus, the qualitative observations played an interpretive role, contributing to an understanding of how pedagogical practices translated into actual experiences of engagement and learning, as well as helping to explain patterns identified in the questionnaire responses.

3.4. Data Analysis Procedures

The data analysis followed a sequential strategy, initially treating the quantitative and qualitative components independently and subsequently integrating them in an interpretive phase, in line with the logic of convergent triangulation characteristic of mixed-methods designs (Creswell, 2009).

3.4.1. Quantitative Analysis

Data from the questionnaire were analysed using descriptive and inferential statistics. In the first stage, measures of central tendency (mean) and dispersion (standard deviation) were calculated for each statement, with the aim of providing an overall characterisation of students' perceptions of the STEAM subject.

Given the characteristics of the sample—moderate size, independent groups, and no assurance of normality in the distribution of responses on ordinal Likert scales—non-parametric statistical procedures were adopted. In particular, the Mann–Whitney U test was used to compare the distributions of responses between boys and girls, an approach recommended when the normality assumptions required by parametric tests are not met (Nachar, 2008).

In addition to statistical significance (p-value), effect sizes were considered using Cliff's delta, allowing the practical magnitude of the observed differences to be assessed. This option aimed to avoid interpretations based exclusively on statistical significance, which is particularly relevant in studies with limited sample sizes, where small differences may fail to reach significance or, conversely, statistically significant differences may have limited educational impact. The interpretation of δ values followed conventional criteria: values below 0.147 were considered negligible, values between 0.147 and 0.33 small, values between 0.33 and 0.474 medium, and values above 0.474 large (Romano et al., 2006).

The analysis was conducted at the level of each individual statement and, when relevant, through organisational thematic groupings, consistent with the formative nature of the instrument and the exploratory aim of the study.

3.4.2. Qualitative Analysis

The field notes were subjected to an interpretive thematic analysis (Braun & Clarke, 2021), with the aim of identifying recurring patterns in students' participation and engagement dynamics throughout the implementation of the STEAM subject. The records were reviewed iteratively, seeking to identify evidence related to the general acceptance of the subject, students' motivation and engagement, preferences regarding the format of the activities, and the cognitive engagement associated with skills development.

The analysis combined categories previously aligned with the aims of the study with categories emerging from the observation records themselves. In a first stage, the observed episodes were grouped into three main dimensions: general acceptance, motivation, and engagement; preferences regarding the format of the activities; and cognitive engagement and skills development. Subsequently, the third dimension was broken down into five subdimensions: reasoning and critical thinking; autonomy and problem-solving; creativity; engagement in specific activities; and interdisciplinarity and scientific concepts.

The most representative episodes were organised according to these analytical dimensions and subdimensions, making it possible to structure the interpretation of the qualitative data and to illustrate the results with descriptive excerpts from the field notes.

Because the observation protocol was designed to characterise students' overall experiences rather than to compare gender groups, the qualitative analysis did not include systematic comparisons between boys and girls. Consequently, interpretations regarding similarities and differences between boys and girls are based primarily on questionnaire data, while the qualitative findings serve a contextual and complementary role.

Given the dual role of the researcher as both teacher and observer, particular attention was paid to minimising potential sources of bias. Field notes were recorded systematically throughout the implementation of the subject and subsequently organised according to predefined analytical dimensions derived from the study objectives. This procedure helped to focus observations on observable behaviours and interactions rather than on general impressions. Furthermore, the qualitative findings were interpreted alongside the quantitative results, allowing for methodological triangulation and strengthening the credibility of the interpretations presented. Although these procedures cannot completely eliminate the influence of the teacher–researcher role, they were adopted to enhance the transparency and credibility of the qualitative analysis.

This systematisation aimed to make observable behavioural patterns explicit, reducing the risk of impressionistic or anecdotal interpretations. Figure 1 presents the conceptual framework used to organise and analyse the field notes.

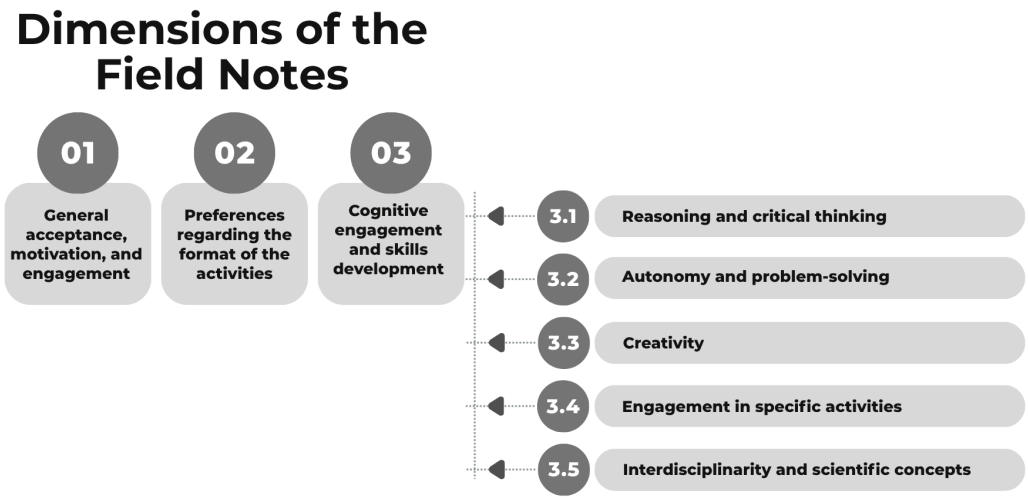


Figure 1. Schematic representation of the dimensions and subdimensions used in the analysis of the field notes.

3.4.3. Data Integration

In the final stage, the quantitative and qualitative results were integrated in a complementary manner. The trends identified in the questionnaire responses were compared with observational evidence collected throughout the lessons, allowing the results to be contextualised and interpreted in greater depth.

This integration sought to strengthen the robustness of the conclusions by exploring convergences between self-reported perceptions and behaviours that were actually observed, as well as by clarifying any discrepancies. Thus, the combination of methods enabled a more comprehensive understanding of students' experience in the STEAM subject than would have been possible through a single source of data.

3.5. Description of the Implementation

The curricular design of the STEAM subject was based on an interdisciplinary approach, integrating content from Physical and Chemical Sciences, Natural Sciences, Mathematics, Visual Arts, and Digital Technologies. The organisation of the activities followed principles of active and student-centred teaching, privileging methodologies such as project-based learning, problem-solving, prototype construction, and the creative exploration of solutions.

Consistently, the proposed tasks sought to:

i. Articulate scientific concepts with everyday situations;
ii. Promote collaborative work in small groups;
iii. Involve students in processes of planning, experimentation, and iteration;
iv. Value both analytical reasoning and creative expression.

Overall, the subject was conceived as an experimental and collaborative learning space in which students assumed an active role in the construction of knowledge, exploring curricular concepts through practical and interdisciplinary challenges.

Tables 1 and 2 provide a summary of the activities developed in each grade level, describing the type of task and the main competencies mobilised. These activities should not be understood as isolated episodes, but rather as part of a continuous pedagog-

ical sequence aimed at the progressive development of scientific, technological, and creative competencies.

Table 1. STEAM activities developed in Grade 7.

Activity	Description	Competencies/Objectives
Construction of polyhedra (straws)	Group construction of three-dimensional geometric figures using straws and adhesive tape.	Consolidation of Mathematics content, spatial reasoning, teamwork and time management.
Balloon car	Planning and construction of air-powered cars, based on prior research and simple materials.	Application of physics concepts, namely force and motion; problem-solving; and creativity and design.
Solar System to scale	Representations of the Solar System, in terms of size and distance, using Paint 3D and maps of Portugal and Europe.	Articulation of Physical and Chemical Sciences, Mathematics, and Geography; digital literacy; and critical thinking.
Three-dimensional model of a volcano	Construction of digital volcano models using Paint 3D.	Consolidation of Natural Sciences concepts; three-dimensional visualisation; and creativity.
Construction of loudspeakers	Group project involving exterior design, calculation of areas and volumes, and circuit assembly.	Integration of Mathematics, Visual Education, and Physics; collaboration; and technological problem-solving.
Urban water cycle (Minecraft)	Creation of wastewater treatment plants and water treatment plants in a collaborative virtual environment.	Practical application of Natural Sciences concepts; collaborative work; digital literacy; and creativity.

Table 2. STEAM activities developed in Grade 8.

Activity	Description	Competencies/Objectives
Newspaper bridge	Group construction of a resistant bridge using newspapers and adhesive tape, tested with standard weights.	Engineering concepts; Physics, namely force and resistance; and collaborative work.
Ovonauta [Egg drop challenge]	Development of protection systems for an egg dropped from a significant height.	Physics, namely air resistance and collisions; Engineering; and creativity and planning.
Molecule modelling	Construction of three-dimensional molecule models using Paint 3D.	Consolidation of Chemistry content, namely atoms and molecules; three-dimensional representation; and digital literacy.
Eukaryotic cell modelling	Creation of digital models of animal or plant cells with identified organelles.	Natural Sciences; visual thinking; and the creative use of digital tools.
Christmas town model with micro:bit	Construction of a themed model with simple automated mechanisms, such as lighting, barriers, and a train.	Programming and robotics; integration of Art, Mathematics, and Engineering; and creative collaboration.
Smart house	Construction of a model of an automated house with simulated home automation.	Engineering and programming; technological awareness; and problem-solving in a real-world context.
Three-dimensional model of the human eye	Digital representation of anatomical structures using Paint 3D.	Physical and Chemical Sciences, namely optics and vision; digital competencies; and anatomical visualisation.

4. Results

4.1. Qualitative Results: Observation of Students' Engagement

The analysis of the qualitative data revealed consistent patterns of acceptance, motivation, and engagement throughout the implementation of the STEAM subject. Following the analytical framework presented in Figure 1, the results were organised into three main dimensions: (i) general acceptance and motivation, (ii) preferences regarding the format of the activities, and (iii) cognitive engagement and skills development. The qualitative findings presented below are intended to characterise students' overall experiences in the STEAM subject. As the observational data were not analysed through a gender-comparative lens, these results should be understood as contextual evidence regarding participation and engagement rather than as a systematic comparison between boys and girls.

4.1.1. General Acceptance and Motivation

The analysis of the field notes showed a positive reception of the STEAM subject from the very first sessions. This acceptance was reflected in the enthusiasm shown by students, their voluntary participation in the proposed tasks, and frequent collaboration among peers. Students demonstrated a willingness to begin activities autonomously, discuss strategies in groups, and persist in solving challenges before asking the teacher for support.

At several points, students acknowledged the appropriateness of the activities developed throughout the year. One participant stated that the tasks "were appropriate because they were not easy, but they were not extremely difficult either, [and were] well organised" (Student 2), suggesting that the level of challenge was perceived as balanced and accessible. This idea is relevant, as it points to a productive relationship between challenge and motivation: the activities were not understood as merely playful or simple, but as both challenging and achievable.

Motivation also seemed to be associated with the active, practical, and open-ended nature of the subject. The possibility for students to make decisions, choose strategies, and participate directly in constructing solutions contributed to greater engagement, as suggested by the statement: "I think the activities motivated us to learn more about the subject" (Student 8). This excerpt shows that the agency given to students acted as a motivating element, encouraging ownership of the tasks and commitment to the learning process.

At various moments, students associated the subject with a way of learning that differed from more expository approaches or those centred on the textbook. Practical learning was perceived as more meaningful, as it allowed students to understand scientific content through experimentation, construction, and the resolution of concrete problems. Thus, acceptance of the subject was not limited to interest in the activities themselves; it was also related to the perception that these activities made the content more understandable, relevant, and closer to students' own experience.

4.1.2. Preferences Regarding the Format of the Activities

The qualitative data indicate a clear preference for activities involving physical construction and the manipulation of materials. These tasks generated immediate engagement, high levels of interaction among group members, and a spontaneous division of roles. Activities involving prototyping, the construction of structures, vehicles, models, or experimental devices were particularly valued, as they allowed students to transform ideas into concrete objects and directly test the solutions they had designed.

This preference was also evident in students' statements. One participant said that they enjoyed "building things with [their] hands" (Student 3), while another explained his preference for practical activities by stating: "I prefer doing things, being the one doing

them, handling them. . .” (Student 6). These excerpts show that the value attributed to practical activities did not derive solely from their manipulative nature, but also from the sense of control, direct participation, and ownership of the construction process.

This preference may be interpreted in light of three main aspects. First, hands-on activities provided immediate feedback, allowing students to quickly understand whether the solution worked or needed adjustment. Second, they supported processes of trial, error, and reformulation, in which failure was integrated as a natural part of learning. Third, they allowed different forms of participation, enabling students with diverse profiles to contribute through design, assembly, research, organisation, calculation, or testing.

By contrast, some activities focused exclusively on digital tools generated less initial enthusiasm and were sometimes perceived as more demanding, abstract, or less stimulating. However, this tendency was not absolute. Some students recognised the interest of certain digital activities, especially when these allowed exploration, creativity, or collaboration.

Thus, the results suggest that students’ preferences were not organised simply around an opposition between manual and digital activities. The decisive factor seemed to be the degree of active participation, creativity, autonomy, and collaboration afforded by each task. More open-ended and collaborative digital environments, such as Minecraft Education, approximated the patterns of engagement observed in hands-on activities, as they enabled decision-making, negotiation, collective construction, and joint problem-solving.

4.1.3. Cognitive Engagement and Skills Development

The observations revealed multiple forms of cognitive engagement throughout the implementation of the STEAM subject. Students were frequently confronted with challenges that required planning, hypothesis formulation, decision-making, solution testing, and strategy reformulation. This engagement became particularly visible in situations of difficulty, when the outcomes obtained did not match expectations, and groups had to rethink their choices.

Students’ statements reinforce this interpretation. One participant noted that, in the activities, “we had to reason in order to see how we could do it” (Student 1), highlighting the cognitive demand associated with solving the challenges. Another student explicitly related error to the development of thinking, stating that “when we make mistakes”, we are able to find “a different way of reasoning” (Student 9). These excerpts suggest that the tasks were not limited to the execution of instructions but involved processes of analysis, reflection, and the reconstruction of strategies.

The logic of trial and error was particularly relevant in the practical activities. Students tested different solutions, evaluated the results, and adjusted their procedures until they achieved a functional product or one more suited to the proposed objective. This dynamic is illustrated by comments such as: “I had several stones and I tested different stone sizes” (Student 7) and “I was trying in several ways, but I could not do it. [. . .] Until I managed to discover the final product” (Student 8). Error was therefore often integrated as a learning opportunity, promoting iterative processes of experimentation and improvement.

Autonomy also emerged as a relevant competence. Students searched for additional information, adapted available materials, made decisions within their groups, and took responsibility for developing solutions. The statement “I researched [. . .] I came to understand how it worked” (Student 1) illustrates the connection between autonomous research and the understanding of the phenomena involved. This dimension is consistent with the open-ended nature of STEAM activities, in which students were encouraged to explore their own solutions and take greater responsibility for the work process.

Manifestations of creativity were also observed, both in the design of the solutions constructed and in the adaptation of materials and exploration of different configurations

to optimise outcomes. Creativity did not emerge only as an aesthetic dimension but as a functional competence, mobilised to solve problems, overcome limitations, and produce original solutions. At the same time, the activities supported the interdisciplinary integration of knowledge, with students mobilising concepts from Physics, Natural Sciences, Mathematics, and Technologies to understand, build, and justify the solutions developed.

Taken together, the qualitative data suggest that the STEAM subject provided an active, participatory, and cognitively demanding learning environment. Students assumed a central role in the construction of knowledge, engaging in processes of experimentation, research, collaboration, decision-making, and strategy reformulation. These results reinforce the idea that STEAM activities, when structured around practical and interdisciplinary challenges, can support not only students' motivation but also the development of cognitive, social, and creative competencies relevant to science learning.

4.2. Quantitative Results: Overall Perceptions of the STEAM Subject

The analysis of the questionnaire responses made it possible to characterise students' overall perceptions of their experience in the STEAM subject. The Table A1 in Appendix A presents, for each statement, the descriptive statistics by gender and for the total sample (N = 82), as well as inferential indicators, namely the Mann–Whitney U test, p-value, and effect size using Cliff's δ.

Overall, the results (presented in Table 3) show a generally positive evaluation of the subject, with most total mean scores above the midpoint of the scale (1–6). In terms of acceptance, statement A1 ("I like STEAM activities") presents a favourable total mean score (M_total = 4.48; SD = 1.26), suggesting an overall positive reception of the activities developed.

Across the items concerning articulation with other subjects, students tended to recognise the contribution of STEAM to their understanding of content from other areas, although this varied across subjects. For example, A4.1, referring to Physical and Chemical Sciences, shows a relatively high overall score (M_total = 4.41; SD = 1.39), whereas A4.2, referring to Natural Sciences, presents a more moderate mean score (M_total = 3.74; SD = 1.47). In A4.3, referring to Mathematics, and A4.4, referring to Visual Education, mean scores again fall within positive levels (M_total = 4.00; SD = 1.36 and M_total = 4.35; SD = 1.43, respectively). This pattern suggests that students' perception of the contribution of STEAM to "better understanding" content depends, to some extent, on the type of content and on the subject with which the activity is connected.

Indicators directly related to students' engagement and action in the tasks consistently reached the highest values. Effort in STEAM classes (A7.1) stands out with a high total mean score (M_total = 5.18), indicating strong student engagement during the sessions. Similarly, the perception of good performance in practical activities (A10) was also highly favourable (M_total = 5.04). In addition, the value attributed to autonomy and agency is reflected in the high mean score obtained for A24, concerning the free activity, in which students clearly highlighted the importance of being able to choose and decide what to do (M_total = 5.06). Taken together, these indicators reinforce the idea that the subject was experienced as a space for active participation and hands-on learning, with high behavioural engagement and perceived practical effectiveness.

The use of educational technologies was also valued. Students reported a strong preference for using technologies during lessons (A8: M_total = 5.02) and a positive perception of their motivational impact (A9: M_total = 4.70). These results are consistent with the central role of digital tools in the design of the activities and suggest that, for most students, technological resources functioned as a facilitating element for interest and participation.

Table 3. Summary of the questionnaire results.

Item	Statement	Δ*M* *	*p*	Cliff's *δ*
A1	I like STEAM activities.	−0.21	0.498	−0.084
A4.1	STEAM classes help me understand some Physical and Chemical Sciences content.	−0.40	0.311	−0.127
A4.2	STEAM classes help me understand some Natural Sciences content.	−0.49	0.143	−0.186
A4.3	STEAM classes help me understand some Mathematics content.	−0.34	0.338	−0.121
A4.4	STEAM classes help me understand some Visual Education content.	−0.13	0.950	−0.008
A5.1	STEAM classes motivate me to study and learn new Physical and Chemical Sciences content.	−0.50	0.212	−0.158
A5.2	STEAM classes motivate me to study and learn new Natural Sciences content.	−0.42	0.239	−0.149
A5.3	STEAM classes motivate me to study and learn new Mathematics content.	−0.47	0.210	−0.159
A5.4	STEAM classes motivate me to study and learn new Visual Education content.	−0.21	0.581	−0.070
A6.1	I consider it important for my future to learn what is addressed in STEAM classes.	−0.17	0.604	−0.065
A7.1	I make an effort in STEAM classes.	+0.51	0.004	−0.337
A8	I like using technologies, such as computers, tablets, etc., during STEAM classes.	−0.44	0.075	−0.215
A9	Using technologies in class motivates me to learn more.	−0.40	0.197	−0.160
A10	I perform well in practical activities.	+0.33	0.038	−0.241
A13.1	I think learning STEAM is important because it stimulates my thinking/reasoning.	+0.23	0.266	−0.134
A15	I like STEAM classes because the teachers propose varied tasks.	−0.21	0.809	−0.030
A16	I think my autonomy increases through STEAM classes.	−0.06	0.758	−0.038
A17	STEAM classes increase my creativity.	−0.16	0.798	−0.032
A18	I consider that the interdisciplinary work I carry out in STEAM classes will be important for my future profession.	−0.13	0.539	−0.078
A24	I liked being able to choose what to do in the free STEAM activity.	+0.09	0.519	−0.077
A29	I liked knowing that there were scientific concepts behind the activities I carried out.	−0.80	0.072	−0.226
A30	I understood the scientific concept behind the activities carried out.	−0.52	0.212	−0.157
A31	It was possible to learn science through the STEAM activities.	−0.61	0.104	−0.201

* Δ*M* = *M*_female − *M*_male.

In the domain of transversal competencies, students recognised STEAM's contribution to autonomy (A16: *M*_total = 4.37) and creativity (A17: *M*_total = 4.56), indicating that the subject was perceived as promoting competencies beyond the strictly conceptual domain.

With regard to conceptual learning, the results suggest that students identified the presence of science underlying the tasks and reported understanding the associated concepts, although with slightly more moderate mean scores than those found for engagement-related dimensions. For example, statement A30 ("I understood the scientific concept behind the activities carried out") presents a total mean score of *M*_total = 4.12 (*SD* = 1.44), and statement A31 ("It was possible to learn science through the STEAM activities")

presents M_total = 4.54 (SD = 1.30), indicating that, overall, students considered that they had learned scientific content through the activities.

In contrast with the indicators of participation and satisfaction, the perceived specific future relevance of the STEAM subject shows more moderate values (M_total = 3.93), suggesting that, although the subject was valued as a learning experience, not all students recognised it as a central element in their future pathway.

In this sense, the overall quantitative results indicate a broadly positive evaluation of the subject, with particularly high values in dimensions associated with engagement, appreciation of practical activities, student agency, and the use of technologies. Dimensions related to conceptual learning and future relevance present more moderate, although still positive, values, suggesting that students perceived the subject as a motivating and formative learning context.

4.3. Quantitative Results: Comparison Between Boys and Girls

To examine possible gender differences in perceptions of the STEAM subject, responses from boys (N = 46) and girls (N = 36) were compared using the non-parametric Mann–Whitney U test. To complement the analysis of statistical significance, effect sizes were also calculated using Cliff's δ, allowing the practical magnitude of the observed differences to be estimated. The full results are summarised in Table 3.

Overall, the response patterns revealed a high degree of similarity between the two groups. The vast majority of statements showed no statistically significant differences ($p \geq 0.05$) and displayed negligible or small effect sizes ($|\delta| < 0.20$), suggesting practical equivalence between boys and girls in their perceptions of the interest, usefulness, and impact of the subject. This cross-cutting pattern indicates that both groups experienced the subject in a comparable way in terms of motivation, engagement, use of technologies, and skills development.

Nevertheless, statistically significant differences were observed in two indicators directly associated with engagement in the activities. In statement A7.1 ("I make an effort in STEAM classes"), girls obtained a higher mean score (M = 5.47) than boys (M = 4.96), a statistically significant difference (p = 0.004) accompanied by a moderate effect size ($\delta = -0.337$). This result suggests higher levels of behavioural engagement among female students.

Similarly, regarding perceived performance in practical activities (A10), girls reported higher values (M = 5.22) than boys (M = 4.89), with a significant difference (p = 0.038) and a small-to-moderate effect size ($\delta = -0.241$). This indicates a higher self-perception of practical effectiveness among female students, although the magnitude of the difference was limited.

For the remaining items, differences between means were small and inconsistent. Some conceptual indicators or items related to content understanding showed slight trends favouring boys, whereas dimensions related to effort, appreciation of activities, and satisfaction tended to favour girls; however, these effects were small ($|\delta|$ typically < 0.20) and statistically non-significant. From an interpretive standpoint, these variations do not reflect educationally relevant discrepancies.

The quantitative results comparing the two groups, therefore, point to a balanced scenario in the reported experiences, with broadly similar perceptions between boys and girls and a few indicators slightly more favourable to female students. These data support the interpretation that the implementation of the STEAM subject provided comparable conditions for participation across genders, with no evidence of consistent inequality in students' experiences or perceived outcomes.

5. Discussion of the Results

The results of the present study make it possible to reflect on students' experiences in a STEAM approach integrated into the school curriculum and on the extent to which boys and girls reported similar perceptions regarding engagement and learning. In interpreting these findings, it is important to note that gender-related comparisons are derived primarily from the questionnaire data, whereas the qualitative observations provide contextual evidence regarding students' overall participation and engagement in the STEAM subject. Overall, both the qualitative and quantitative data converge in identifying high levels of acceptance, motivation, and participation in the proposed activities, suggesting that the subject was perceived as a meaningful and distinctive learning space when compared with more traditional approaches.

Regarding the general perception of the subject, the mean scores obtained in the questionnaire indicate consistently positive evaluations, particularly for indicators associated with effort, performance in practical activities, the use of technologies, and the possibility of choice and autonomy in the tasks. These results are aligned with studies that associate active methodologies, project-based learning, and interdisciplinary contexts with higher levels of student motivation and engagement (Barmby et al., 2008; Barron et al., 1998; Holmegaard et al., 2014; Yew & Goh, 2016). Likewise, the appreciation of educational technologies and practical experiences corroborates evidence on the potential of STEAM to make learning more contextualised, creative, and relevant (Henriksen et al., 2015; LaForce et al., 2016).

The qualitative analysis of classroom observations reinforces the interpretation that students generally experienced the STEAM subject as an active and engaging learning environment. However, because the observational data were not analysed through a gender-comparative lens, these findings should be understood as evidence of students' overall experiences rather than as direct evidence regarding similarities or differences between boys and girls.

With regard to the study's central question, the quantitative results provide relatively rare empirical evidence on the sustained implementation of a STEAM subject integrated into the lower secondary curriculum in the Portuguese context. The quantitative results indicate that boys and girls reported broadly similar perceptions across most dimensions examined. Accordingly, interpretations regarding similarities and differences between boys and girls are based primarily on these quantitative findings. Most comparisons between boys and girls revealed no statistically significant differences and showed negligible or small effect sizes, suggesting practical equivalence between the groups. Dimensions such as motivation, interest in the activities, use of technologies, creativity, autonomy, and conceptual understanding displayed very similar patterns across genders.

This result contrasts with international evidence reporting persistent gender disparities in STEM fields, often associated with lower levels of interest, self-confidence, and participation among girls (OECD, 2018, 2019; WEF, 2020a; Xie et al., 2021). In the present study, however, the combined interpretation of statistical significance and effect magnitude indicates that most observed differences are of limited practical relevance, with only occasional discrepancies of small magnitude. These findings appear consistent with studies arguing that collaborative, contextualised, and project-based STEAM environments may support more inclusive and balanced experiences (Bowman et al., 2022; García-Holgado et al., 2024; Hasenhütl et al., 2024).

It is important to note that only two statements showed statistically significant differences, both favouring girls and related to effort in class and perceived performance in practical activities. Even so, the observed effect sizes ranged from small to moderate, suggesting limited practical impact. These results challenge traditional stereotypes that

associate greater technical or experimental competence with boys and are consistent with the possibility that practical, collaborative, and contextualised learning environments may support the participation of a diverse range of students.

In this sense, the data obtained suggest that the pedagogical organisation adopted—characterised by diversified tasks, the integration of creative components, and an emphasis on collaborative work—may have contributed to creating learning conditions in which boys and girls reported broadly similar experiences of participation and engagement. Although causal relationships cannot be established, the results are consistent with the possibility that STEAM approaches integrated into the curriculum and implemented over an extended period may be associated with more balanced perceived educational experiences across genders. This type of sustained curricular implementation remains relatively underrepresented in the literature, which tends to privilege short-term interventions or one-off initiatives.

However, these findings should be interpreted with caution. The case study design, the absence of a pre-test and control group, and the use of self-report measures prevent the establishment of causal relationships between attendance in the subject and the observed outcomes. In addition, the fact that the study was carried out in a single school context, with a convenience sample, limits the statistical generalisability of the results. Moreover, the study was conducted in a private school serving a relatively homogeneous and socioeconomically advantaged student population. As a result, the broadly similar perceptions reported by boys and girls may reflect characteristics of this particular educational context and should not be assumed to apply to public schools or to more socioeconomically diverse settings. Since socioeconomic and contextual factors may interact with gender in shaping students' experiences, further research is needed to examine whether similar patterns emerge across different educational environments. Furthermore, the study relied primarily on students' self-reported perceptions and did not directly assess learning gains, STEM aspirations, self-efficacy, science identity, future educational choices, or other outcomes frequently associated with participation in STEM education. Consequently, the findings should be interpreted as evidence of how students perceived their experiences within the STEAM subject rather than as evidence of changes in these broader dimensions. Thus, the data should be understood as contextualised and exploratory evidence, aimed more at understanding processes than at making universal inferences.

The results suggest that the implementation of a STEAM subject based on active methodologies was associated with high levels of engagement and broadly balanced experiences between boys and girls. These findings reinforce the value of interdisciplinary, practical, and student-centred approaches as promising strategies for promoting meaningful and potentially more inclusive learning in scientific and technological contexts.

Beyond the contextual description of the results, the present study also contributes to conceptual reflection on the potential relationship between STEAM pedagogies and educational equity. Although the present study did not directly measure equity-related constructs such as belonging, self-efficacy, science identity, science capital, or perceived competence, the broadly similar perceptions reported by boys and girls are consistent with the possibility that such environments may support more balanced learning experiences. The data are consistent with the possibility that the systematic curricular integration of practical, collaborative, and interdisciplinary activities may broaden opportunities for participation, offering multiple points of entry and diversified forms of engagement that accommodate different interests and learning styles. In this sense, rather than merely constituting a motivational strategy, STEAM may be understood as a potentially inclusive approach that can provide multiple opportunities for participation and engagement. This interpretation frames the results not only as localised evidence of a particular educational experience, but also as a contribution to the broader debate on how curriculum design and

pedagogical practices may contribute to supporting more equitable educational experiences in science education.

6. Conclusions

The present study sought to analyse students' perceptions of the implementation of a STEAM subject integrated into the lower secondary education curriculum, as well as to explore possible differences between boys and girls in their experiences within this context. Overall, the results point to a positive evaluation of the subject, characterised by high levels of motivation, engagement in practical activities, appreciation of the use of technologies, and recognition of the contribution of the tasks to the development of transversal competencies, such as autonomy, creativity, and problem-solving.

With regard to gender, the quantitative analyses revealed broadly similar patterns between boys and girls. Most comparisons did not show statistically significant differences and presented negligible or small effect sizes, suggesting practical equivalence between groups. Even in the few indicators where significant differences were found, the observed magnitudes were small or moderate, suggesting limited practical impact. These results do not indicate any systematic disadvantage for either gender and are consistent with the interpretation that the subject provided comparable conditions for participation for all students. However, the absence of statistically significant differences should not be interpreted as direct evidence of gender equity. Rather, these findings reflect students' perceptions of their experiences within the STEAM subject and do not constitute direct evidence of learning gains, changes in aspirations, self-efficacy, science identity, or future educational trajectories.

In this sense, the data obtained reinforce the potential of STEAM approaches, grounded in active, interdisciplinary, and collaborative methodologies, to create motivating learning environments that may support the engagement of different student profiles. The broadly similar perceptions reported by boys and girls are consistent with the possibility that such environments may support balanced perceived educational experiences. Although they do not allow causal relationships to be established, the results suggest that this type of pedagogical organisation may contribute to balanced and meaningful educational experiences. Nevertheless, the findings should be interpreted with caution, as the study did not include baseline measures, behavioural indicators, achievement outcomes, or longer-term measures that would allow a more comprehensive assessment of gender equity. These characteristics, together with the fact that the study was conducted in a single private school with a relatively homogeneous and socioeconomically advantaged student population, limit the generalisability of the results and call for caution when interpreting their implications for gender equity. Consequently, the findings should not be assumed to transfer directly to public schools or to more socioeconomically diverse educational contexts.

Future research could deepen these findings through larger and more diverse samples, longitudinal or quasi-experimental designs, and additional assessment instruments, making it possible to understand more robustly the relationship between STEAM approaches and students' engagement, learning, and equitable participation in scientific and technological fields.

In summary, the study contributes to understanding students' experiences of a curriculum-integrated STEAM subject in a real classroom context. The findings indicate broadly similar perceptions of participation, engagement, and learning among boys and girls, while also highlighting the need for further research using additional indicators of equity and more robust research designs.

Author Contributions: Conceptualization, M.D.H. and P.S.C.; methodology, M.D.H. and P.S.C.; validation, I.S., J.L.A. and P.S.C.; formal analysis, M.D.H., I.S. and J.L.A.; investigation, M.D.H.;

Resources, M.D.H. and P.S.C.; data curation, M.D.H.; writing—original draft preparation, M.D.H. and I.S.; writing—review and editing, I.S. and J.L.A. and P.S.C.; supervision, P.S.C. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by national funds through FCT—Fundação para a Ciência e a Tecnologia, I.P., in the framework of the projects UID/04564/2025 (CFisUC) with DOI identifier 10.54499/UID/04564/2025, UID/04968/2025 (IFIMUP) with DOI identifier 10.54499/UID/04968/2025 and UID/00194/2025 (CIDTFF) with DOI identifier 10.54499/UID/00194/2025.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and with the ethical principles for educational research outlined by the British Educational Research Association (BERA). Prior to implementation, the investigation was authorised by the school's pedagogical council and board. The council did not issue any formal reference number or documentation associated with this authorisation.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The authors will provide relevant data upon reasonable request.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1. Overall questionnaire results.

Item	Statement	Group	*N*	*M*	*SD*	Δ*M*	*U*	*p*	*δ*
A1	I like STEAM activities.	Male	46	4.59	1.17	−0.21	758.5	0.498	−0.084
		Female	36	4.38	1.38				
		Total	82	4.48	1.26				
A4.1	STEAM classes help me understand some Physical and Chemical Sciences content.	Male	46	4.59	1.24	−0.40	723	0.311	−0.127
		Female	36	4.19	1.55				
		Total	82	4.41	1.39				
A4.2	STEAM classes help me understand some Natural Sciences content.	Male	46	3.96	1.38	−0.49	674.5	0.143	−0.186
		Female	36	3.47	1.56				
		Total	82	3.74	1.47				
A4.3	STEAM classes help me understand some Mathematics content.	Male	46	4.15	1.21	−0.34	728	0.338	−0.121
		Female	36	3.81	1.53				
		Total	82	4.00	1.36				
A4.4	STEAM classes help me understand some Visual Education content.	Male	46	4.41	1.28	−0.13	821.5	0.950	−0.008
		Female	36	4.28	1.61				
		Total	82	4.35	1.43				
A5.1	STEAM classes motivate me to study and learn new Physical and Chemical Sciences content.	Male	46	4.22	1.52	−0.50	697	0.212	−0.158
		Female	36	3.72	1.75				
		Total	82	4.00	1.63				
A5.2	STEAM classes motivate me to study and learn new Natural Sciences content.	Male	46	3.67	1.52	−0.42	704.5	0.239	−0.149
		Female	36	3.25	1.59				
		Total	82	3.49	1.56				

Table A1. *Cont.*

Item	Statement	Group	*N*	*M*	*SD*	Δ*M*	*U*	*p*	*δ*
A5.3	STEAM classes motivate me to study and learn new Mathematics content.	Male	46	3.89	1.45	−0.47	696	0.210	−0.159
		Female	36	3.42	1.63				
		Total	82	3.68	1.54				
A5.4	STEAM classes motivate me to study and learn new Visual Education content.	Male	46	4.04	1.62	−0.21	770	0.581	−0.070
		Female	36	3.83	1.70				
		Total	82	3.95	1.65				
A6.1	I consider it important for my future to learn what is addressed in STEAM classes.	Male	46	4.00	1.38	−0.17	774	0.604	−0.065
		Female	36	3.83	1.42				
		Total	82	3.93	1.40				
A7.1	I make an effort in STEAM classes.	Male	46	4.96	0.97	+0.51	549	0.004	−0.337
		Female	36	5.47	0.74				
		Total	82	5.18	0.90				
A8	I like using technologies, such as computers, tablets, etc., during STEAM classes.	Male	46	5.22	1.01	−0.44	650	0.075	−0.215
		Female	36	4.78	1.29				
		Total	82	5.02	1.15				
A9	Using technologies in class motivates me to learn more.	Male	46	4.87	1.05	−0.40	695.5	0.197	−0.160
		Female	36	4.47	1.34				
		Total	82	4.70	1.19				
A10	I perform well in practical activities.	Male	46	4.89	0.77	+0.33	628.5	0.038	−0.241
		Female	36	5.22	0.68				
		Total	82	5.04	0.74				
A13.1	I think learning STEAM is important because it stimulates my thinking/reasoning.	Male	46	4.96	1.13	+0.23	717	0.266	−0.134
		Female	36	5.19	1.04				
		Total	82	5.06	1.09				
A15	I like STEAM classes because the teachers propose varied tasks.	Male	46	4.57	1.21	−0.21	803	0.809	−0.030
		Female	36	4.36	1.55				
		Total	82	4.48	1.36				
A16	I think my autonomy increases through STEAM classes.	Male	46	4.39	1.29	−0.06	796.5	0.758	−0.038
		Female	36	4.33	1.55				
		Total	82	4.37	1.40				
A17	STEAM classes increase my creativity.	Male	46	4.63	1.25	−0.16	801.5	0.798	−0.032
		Female	36	4.47	1.50				
		Total	82	4.56	1.36				
A18	I consider that the interdisciplinary work I carry out in STEAM classes will be important for my future profession.	Male	46	3.63	1.45	−0.13	763.5	0.539	−0.078
		Female	36	3.50	1.50				
		Total	82	3.57	1.47				

Table A1. *Cont.*

Item	Statement	Group	*N*	*M*	*SD*	Δ*M*	*U*	*p*	*δ*
A24	I liked being able to choose what to do in the free STEAM activity.	Male	46	5.02	1.09	+0.09	764	0.519	−0.077
		Female	36	5.11	1.14				
		Total	82	5.06	1.10				
A29	I liked knowing that there were scientific concepts behind the activities I carried out.	Male	46	4.41	1.17	−0.80	641	0.072	−0.226
		Female	36	3.61	1.84				
		Total	82	4.06	1.54				
A30	I understood the scientific concept behind the activities carried out.	Male	46	4.35	1.18	−0.52	698.5	0.212	−0.157
		Female	36	3.83	1.68				
		Total	82	4.12	1.44				
A31	It was possible to learn science through the STEAM activities.	Male	46	4.80	1.00	−0.61	661.5	0.104	−0.201
		Female	36	4.19	1.55				
		Total	82	4.54	1.30				

Note. Δ*M* = *M*_female − *M*_male.

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