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# Fostering Critical Reflection in Primary Education through STEAM Approaches

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**Abstract:** This paper describes a quantitative study that explores teaching practices in primary education to sustain the hypothesis that students' critical thinking may be activated through individual and group reflection. The study examines the quality of the reflections from primary school students during group processing when participating in Science, Technology, Engineering, Arts, and Math (STEAM) instructional approaches. The project's core methodology lies in scientific (physics) and artistic (dance) instructional activities which were executed in a continuous reflective and cooperative learning environment. The educational approach was refined by analyzing the reflective discussions from focus groups where descriptive, argumentative, reflective and critical reflective knowledge about acquired knowledge, competences, beliefs, attitudes and emotions were considered. While the educational intervention proved that 1st-year (K-7) students essentially reflected at the level of description, 3rd-year (K-9) and 5th-year (K-11) students, however, attained higher levels of individual critical reflection development than initially anticipated. The STEAM approaches were found to produce significant use and understanding of both science and artistic concepts and to increase a sense of competence readiness and a perception of modes of cooperation such as individual responsibility and promotive interaction.

**Keywords:** learning; STEAM education; competence; critical reflection

## 1. Introduction

Reflection is one of the most exciting competences in primary, secondary and tertiary education systems because it empowers students in their personal learning [1]. Reflective learning relates to the needs of an ever-advancing world by ensuring a constant understanding of continuously changing social and environmental paradigms and where experiential knowledge is activated through continuous inquiring and self-assessment [2,3]. In the educational context, knowledge acquisition not only demands inter- and cross-disciplinary approaches and competences [4–7], but also entails transformative instructional approaches [1]. Reflection connects previous and new experiences with existing knowledge and skills; all of which are essential in defining students' specific learning outcomes [8,9]. Reflection can also offer a way of identifying, in terms of acquisition of systems thinking, transversal and specific competences, attitudes and emotions as explicit outcomes, the unique learning style(s) of each student [4]. The complex nature of education requires continuously evaluating environments and societies [1], to ensure increasing inclusivity, reflectivity and democracy to "boost the cognitive and emotional development of children with effects that persist into adulthood" [3] (p. 2).

Promoting STEAM (Science, Technology, Engineering, Arts, and Math) activities relies heavily on integrating the arts into STEM to reshape education in the sciences and humanities, and which are then supported by trans-disciplinary frameworks within which real-world problems can be solved [10]. Perignat and Katz-Buoincontrono [11] postulated that STEAM can enhance students' creativity, critical thinking, innovation, collaboration, and interpersonal communication skills. However, while the educational outputs behind STEAM activities are well established, it can be argued that their development strategies are still a weak point [8]. Continuous independent research and development, cutting-edge projects, mechanisms for curriculum design and transformation, multi-angle course effectiveness verification and contextualized learning are all key educational strategies [12,13], along with strategies based on STEM practices that foster students' results in terms of knowledge, understanding, skills development, values and attitudes [14], that are yet to be fully developed.

Reflective learning can be closely linked to STEAM practices [12]. Through reflection, students can develop and acquire strategic competences [15], skills [6,7], attitudes and emotions [16] concerning their future actions, along with an initial recognition of personal identity [1]. Reflective learning increases self-knowledge and helps to identify correlation between different scientific domains [3], as well as understand the processes of community and society [1,4,17]. These are the basis of connecting the arts to science [3,4]. Reflection, for example, is intended to examine, frame and contextualize scientific questions to answer hypotheses during experimentation, and also to query and reflect on individual responsibility during active experimentation [18,19]. Reflective practices also focus on behavioral, emotional, and social principles to enhance students' engagement as learners [9]. Reflection might create the conditions to define personalized learning pathways for the uptake of knowledge and to develop and acquire of specific competences [3,4]. Reflective practices prompt individual-centered reflection on how to increase one's own engagement as a learner, thus leading to deep learning outcomes [15,20]. Outcomes and skills have both been recognized to positively influence the acquisition of learning [21,22]. Reflective learning, a component of reflection, has a direct implication for the transformation of activity, feelings, emotions, and empathies during experiential action [16,23,24]. Reflection begins by considering one's personal activity, ideas, beliefs and feelings [1], while also considering the processes, mechanisms of various environmental and social contexts [1]. It is widely recognized that students develop higher cognitive processes and activate individual self-knowledge when they pose questions [7], identify problems, find outputs and solutions [6], and produce actions, activities and goals [25].

Reflective learning, in environmental and social contexts, results in focusing and optimizing activities to best impact quality teaching [26]. However, despite this, reflective activities have been poorly explored in STEAM education and the positive impact gained by combining arts and science environments in primary school is still to be recognized. Consequently, this is not reflected in teacher training in the different disciplines, and thus is still a major issue [13,14]. Unlike in secondary and tertiary education, STEAM activities are yet to be effectively contextualized in primary education and this is widely recognized as a seriously underdeveloped educational strategy [3,8]. Interdisciplinary STEAM educational approaches can be used to stimulate individual and group reflection for continued personal development as citizens and enable one to make important decisions in complex settings such as those encountered in environmental education [2,27]. It is especially important that primary students participate in group research using discussions addressed to encourage personal development, awareness and communication skills, all of which are the basis for developing STEAM education [9,10].

STEAM activities embedded with reflection and cooperation as their foundation for scientific and artistic education skills and content [15,19] are found to develop higher levels of thinking and learning among students [8,15,19]. As such, learning takes place in a community-centered environment where both creativity and critical thinking represent a students' development and progress [28]. Teaching the sciences and the arts cooperatively provides primary school students with the opportunity to improve their abilities to interact and communicate with their peers and teachers [29,30]. It also promotes joint thinking and respect for others [8,31] and provides primary school teachers with the skills necessary to assess their students during the process of developing strategies to operationalize contextualized scientific and artistic concepts [32,33]. However, despite such findings for tertiary education [19], little is known about the perception the primary school community has on promoting competences through active approaches to further operationalize students' competences.

The pragmatic notion of reflection was first reported as incorporating reflection to action [34] so as to engage students in a process of continuous learning [1,5]. The works of Kolb [35] and Kolb [36], established the basis for experiential learning as being the active creation of knowledge through the transformation of experiences. Schön [37] described the process of reflecting as a dialogue between thinking and doing [38]. Consequently, learning occurs through action [15,38,39] with learners undergoing experiential cycles several times [26]. In STEM classroom environments, knowledge transformation is mainly based on the early stages of Kolb's model where only concrete experiences are described with almost no processes on reflective observation, abstract conceptualization and/or active experimentation being activated. Some authors [15,40] argued for effective grounded learning environments in which students initiate unique trajectories to learning. Though employing reflective activities in STEM education has been partially explored, this is not the case—despite being highly recommended—for STEAM education [8,41]. Abdulwaked and Nagy [42] and Bassachs et al. [8] noted that the impact scientific laboratory classes have on student' progress is yet to be recognized, and the role formal and non-formal education plays in engineering and science education should be reformulated. Thuneberg et al. [10] and Perignat and Katz-Buonincontro [11] report that in STEAM education, students should be experiencing constructivist pedagogy to gain a sense of belonging, self-esteem and autonomy, and, in return, this kind of education would serve as a motivating factor towards pursuing professional identity.

A hybrid combination of STEAM processes might produce modes of effective learning [1,8,22,33]. For instance, arts education could include learning outcomes in creativity and critical thinking [11], because grounded learning appears when there is a concrete situation. For example, the learner specifies the learning goals for the transformation of some beliefs, experiences and/or prior knowledge (about themselves, the context or profession), argues and transfers learning based on scientific evidence and also implements improving alternatives and argues them without shortcomings and mistakes, thus closing the reflective cycle [5]. As stated by Crouch and Mazur [43], students might develop complex reasoning skills when they are effectively engaged with the methodology, objectives and goals of the experience. Therefore, it is important to engage students in reflection processes to confront them with dynamic cross-instructional approaches with which to confront environmental and social questions.

The aim of this study is then twofold: (i) to examine the quality of the reflections of primary school students to discern the degree of reflection for K-7 (1st year), K-9 (3rd year) and K-11 (5th year) primary school students through STEAM instructional approaches, and (ii) to compare, quantitatively, reflection levels between 1st-, 3rd- and 5th-year primary school students to determine the level of the students' critical thinking and sense of competence readiness.

## 2. Materials and Methods

### *2.1. Participants*

Ninety K-7 (1st year), K-9 (3rd year) and K-11 (5th year) primary-school students (30 students per year and two classes per year) were supervised by the authors of this manuscript and by two teachers for each group: one a specialist in science education and the other in physical education. The distribution by sex was as follows: K-7 classes had 43.4% girls and 56.6% boys; in the K-9 classes, 52.3% were girls and 47.7% boys; in the K-11 classes, 55.4% were girls and 44.6% boys. The mean age for the K-7 students was 6.34 years, for the K-9 students 8.60 years and for the K-11 students 10.71 years. Ethnicity was more varied in the group of 1st-year students (29.4%), while for the 3rd-year students it was 25% and 13% for the 5th-year students. In the 1st-year class, for example, there were students from Morocco, the People's Republic of China, Nigeria and Senegal.

The classes were selected from a public school associated with the University of Girona. Students from K-7, K-9 and K-11 participated in six groups of 15 students, i.e., two groups of 15 students per year. Through the school coordinator, all the students were informed of the educational approach and objectives, as well as provided with information about all the science experiments, the dance activities, the materials and the issues on reflection through discussions during group processing. In addition, the University of Girona requested permission from the students' families to allow their children to participate in the study and to be recorded during the group processing. Families were also informed about the privacy of the data and that it would be used only for research purposes.

### 2.2. Sequential Methodologies and Conceptual Framework

To facilitate the students' initiation into each scientific experiment, they were first placed and asked to build a conceptual map to reflect on previous knowledge concerning specific scientific parameters. Next, the students were presented with the experiment along with all its variables and their qualities. They then performed the six in-class experiments together and discussed the basis of the scientific experiments. In the subsequent (third stage) group reflection session, the students redrew their initial conceptual map, categorizing the scientific concepts and their qualities. In this activity, both the teacher and the researchers introduced a set of questions to contextualize each experiment. The objective being to promote self-reflection and improve the students' skills in communicating science. Then, in the fourth stage, the students translated the scientific variables (i.e., time, space, mass, velocity, rhythm, etc.) to physical variables and their qualities. In the fifth stage, the groups were asked to cooperatively develop these concepts through dance challenges, which would later be demonstrated to the whole class. During this stage, the students explored and explained the scientific parameters and concepts by creating artistic proposals through movement, which were, in turn, the synergies between the experiments and their interpretations of them. In addition, teachers and researchers promoted the dimensions of cooperative learning, as such, positive interdependence, promotive interaction and individual responsibilities. In alignment with Spanish education policy requirements, mutual respect independent of diverse levels of activity, gender, origin or condition was fostered.

During the final stage of the instructional approach, the students participated in groups of five in an open discussion with the primary school teacher and one of the researchers. The students were asked to reflect on the whole process by expressing their perceptions of the acquisition of scientific contents, the processes related to the experiments, and the process of producing creative developments. They were also asked to think about cooperation and collaboration within the groups, interpersonal relationships, acquired competences, emotions, beliefs and skills. The open discussions lasted for one hour. In all, seventy-two group discussions were recorded; they were transcribed into text and later analyzed by the researchers.

The methodology can be described in four stages (Table 1) each corresponding to the consecutive stages of the educational approach: reflection and exploration of each experiment (stage 1), reflection on both scientific and artistic parameters and their qualities (Stage 2), development of reflective group analysis (stage 3), and reflection on competences, skills and emotions (Stage 4).

In the first stage, the teachers presented the students with each experiment, the taxonomy of concepts and the topics to be covered in a group session. They then asked the students to explicate their prior knowledge concerning their participation in scientific experiments and research and their knowledge about scientific experiments and their qualities. Further comprehension was facilitated by drawing up a conceptual map, with an emphasis on concepts, qualities and contextualization [8], for each scientific experiment. The basis for the educational approaches chosen were STEAM experiments including scientific and artistic frameworks. The six scientific experiments were divided into three well-established fundamentals: experiments to consolidate recently acquired knowledge (the Galileo pendulum, waves and falling objects), and the other three to introduce the new knowledge (circular movement, flowing winds and the inclined plane (Table 2)). Both the scientific and artistic parameters describing the experiments are listed in Table 2. All stages correspond to strands in the Spanish curriculum for science and physical education (where dance is included) promoting the following competences in science: (i) by posing research questions about science, cycle life of organisms in nature, functioning of ecosystems, students should identify main characteristic and dynamical processes and produce quality descriptions and understandings, (ii) explain complex phenomena including their qualities, and begin with the transformation of observations to written/oral communication, (iii) find explanations for the interactions between humans and environment, and the description of basic scientific laboratory procedures and principles behind science, and (iv) participate in cooperative groups, through individual responsibility, supportive member action, dialogical attitude for promotive interaction, arguing and contrasting opinions with peers in continuous feedback with them and the teacher. In addition, the following competences in arts education were also fostered: (i) communicate creatively the basis of experiments using the expressive resources of one's own body, and (ii) participate in cooperative activities around dance reflecting linguistic, corporal–kinesthetic and artistic expression parameters.

**Table 1.** Description of stages based on their research contents.

| Stages | | Content |
|---|---|---|
| Stage 1 | (a) | Explicating the known in-group cooperation (by verbal individual communication) |
| | (b) | Hands-on experimentation (individually and in group cooperation) |
| Stage 2 | (c) | Conceptualization of scientific parameters |
| | (d) | Conceptualization of qualities of scientific parameters |
| | (e) | Contextualization of scientific parameters |
| | (f) | Translation of scientific concept to movement–dance (group cooperation) |
| Stage 3 | (g) | Reflective analysis (written reflection and group conceptual map) |
| Stage 4 | (h) | Reflection on competences, skills, attitudes and emotions |

In the artistic field, for the 1st- and 3rd-year students, the aim is to quantitatively enrich the child's movement, giving priority to the variety of experiences and leaving the students to look for various motor solutions. For a 5th-year student, the quality in the movement is directed to motivate and encourage the effectiveness and the expressiveness of the movement. A 1st-year student must communicate through simple expressive manifestations, while a 3rd-year student must be able to communicate through more elaborate expressive manifestations and a 5th-year student must be able to do so creatively and using all the expressive resources of the body itself. Specifically, 1st-year students should (i) position themselves in space in relation to others using basic topological notions, (ii) balance the body by adopting different postures, controlling tension, relaxation and breathing, and (iii) move, jump, turn, throw, receive, and handle objects in various ways by varying body positions. Meanwhile, a 3rd-year student should (i) orient the space in relation to the position of their classmates and objects using topological notions, and (ii) move, jump and rotate differently through coordinated body movement and propose simple rhythmic structures. Finally, a 5th-year student should (i) adjust body movements to different changes in the conditions of an activity using topological notions, (ii) develop active behaviors to stimulate and adjust one's performance to one's own bodily possibilities and limitations, (iii) move, jump, and turn in a coordinated way by adapting to different scientific experiments, and (iv) represent complex situations using the expressive resources of the body.

In the scientific field, during the first and third years, the learning of procedures must be relevant, while during the fifth year the use of procedures is promoted as a research tool and as a way of conceptualization. Specifically, a 1st-year student should (i) collaborate in groupwork tasks, contrast and value the explanations of others with one's own with respect, and (ii) ask questions about certain facts and phenomena using search strategies data and communicate the results orally, graphically and/or physically. A 3rd-year student should (i) ask questions about the experiments to obtain relevant information through direct and indirect systematic observation, (ii) show initiative, understand the relationships and creativity with other experiments worked on and (iii) value groupwork demonstrating an attitude of cooperation and responsible participation, accepting differences with respect and tolerance for the ideas and contributions of others in dialogues and debates. Finally, a 5th-year student should (i) show initiative and creativity in problem solving, (ii) ask questions about the experiments performed, (iii) assess the relationships with other learning experiences and acquisition and (iv) demonstrate an ability to synthesize the observation(s) and experimentation.

**Table 2.** Scientific experiments with the associated artistic (dance/movement) and scientific concepts.

| Experiment | Dance Concepts | Scientific Concepts |
|---|---|---|
| The Galileo pendulum | Rhythm, synchronization. Order, sequence, and progression. Space, amplitude and time. Control of the moving body. Spatial perception. Orientation and temporal structure. Displacements. Direction and trajectory. | Uniform movement<br>The planets<br>Forces in a body |
| Transversal and longitudinal waves | Fluency of movements, use of space, laterality, spatial orientation. | Waves and sound |
| Falling objects | The intensity or energy of movement, gravity, inertia, and fluidity. Muscle tension and relaxation, body control, balance and imbalance. | Falling object<br>Measurements: longitude and time<br>Learning to classify<br>Real movements<br>Rectilinear movements |
| Circular movement | Planes and body axes, synchronization, rotations and displacements. | Circular movements<br>Equilibrium of forces |
| Flowing winds | Fluidity of movement of the whole body. Shape, body and space. Global and analytical movements. Perception of tension and relaxation. Displacements, turns and jumps. | Movements and energy<br>Real movements<br>Forces in a body |
| Inclined plane | Static and dynamic balance. Intensity, speed, acceleration. Strength and agility. | Equilibrium of forces<br>Rectilinear movements |

### 2.3. Data Analysis

During the final stage of the experiments, reflection was organized with the primary school students communicating to the group their perceptions. Each group discussion was formed by five individuals and the group discussion was managed by the schoolteachers and one member of the research team with the whole process consisting of 72 focus groups. During the group processing, all the individuals were asked to reflect on perceptions including acquisition of scientific and artistic concepts, personal development of competences, skills, beliefs, attitudes, and emotions. Each group processing session lasted an hour. A member from the research team, together with a teacher, participated in the group discussion. The research directed the process of inquiring, consisting of open questions, while, during the process, the primary school teacher was providing support. All the group discussion sessions were videotaped. An initial analysis was carried out in which those perceptions that presented repetition were discarded. The full experiment consisted of a final 374 min video and all the information was fully transcribed for analysis. The coding of the information was undertaken by the research team, in subgroups of two, who initially agreed 93% of the information for students' units and categories [19,44]. Our analysis considered first, units describing either physical education, sciences or general comments on knowledge, methodologies, materials, applications, competence, difficulties, and attitudes. This resulted in a total of 242 units, some of which feature in Table 3. Likewise, this task was undertaken by members of the research team, divided into different subgroups of two members each, who were, for the most part, in an agreement of 97%. Discussion between the first two members and the second two members helped to resolve disagreements and endorse agreement [44]. The level of reflection was assessed using the four scales from Kember et al. [45], in which the level of reflection in the group discussions is likely to contain four categories: descriptive, argumentative, reflective and critical reflective [45,46]. This analysis is already being used to analyze written reflective narratives by pre-service students [6,19]. Using such a model of categories allows for analytical assessment between the four-category scheme related to contents of the four stages described in Table 1.

**Table 3.** Units (sentences) of reflection by students in the areas of science and arts (through dance) education for each level of the reflective learning.

| Area | Level | Unit |
|---|---|---|
| Science education | Description | The force and the axis are linked to movement.<br>Not all the balls fall at the same speed. The big ones are the fastest.<br>The swing of the pendulum depends on how long the wire is, and nothing else.<br>Speed can be fast or slow, but not space.<br>Some waves can move back and forth. |
| | Argumentation | I've learned that when a ball falls inside a tube it goes faster or slower depending on the type of ball and the type of tube.<br>During the wave experiment, I was thinking with the waves in the beach.<br>When we were experimenting with objects in the air, I felt like an airplane.<br>Space, time and velocity are related to movement.<br>Balls move downwards due to gravity. |
| | Reflection | The swing of the pendulum reminds me of the movement of a snake or what DNA looks like.<br>To be able to fly you have to have very large rooms, which is something I don't have.<br>I wonder if the fish also feel or see the waves.<br>The better I understand the concepts of physics the better I incorporate them into my movement.<br>I can't always make movements that express science. |
| | Critical reflection | I learned to build experiments by myself and that with just a few materials you can build an experiment.<br>It's more fun to do the experiments with your teammates than alone.<br>Working as a group means we could fix any complications.<br>In group experiments I feel responsible for the task assigned to me.<br>I would love to be able to build the experiments for myself. |
| Dance education | Description | My arms and body can act like an axis when I turn.<br>Some of the movements need more than one person to be performed.<br>I control the directions of the movement very well.<br>To turn I have to coordinate my head, legs and arms, and to maintain the vertical axis of my body so as not to lose my balance.<br>I rotate faster when my arms are attached to the body. |
| | Argumentation | Everyone is full of axes. You just have to move to see them.<br>Almost all objects can move: fast, slow, right, left, up and down. People too.<br>The movement to the moon is lighter because there is less gravity.<br>When I do turns I imagine that I am a music box dancer, but I can also move in different directions and speeds, it is more fun.<br>It is the gravity that makes us heavy. |
| | Reflection | Without movement many things aren't possible.<br>It's easier to get into physics when you bring it alive.<br>Only when we move around the others can we see the twists.<br>I would never have imagined I could learn about science by dancing.<br>I am able of performing better when I understand the movement in my body. |
| | Critical reflection | It is my responsibility to carry out good dance movements.<br>Movement is not the same as dance, dance requires cooperation.<br>I want more movement activities so that I can talk, discuss with my friends and learn other subjects better.<br>I have realized what I have to do to learn. I have to think, ask questions, give my opinion, listen, communicate and experiment with my body in movement that I have never done.<br>Science motivates me more when I consciously share it with colleagues. |

The descriptive level corresponds to units from stage 1 where the scientific experiments and artistic practices were described by a very simple sentence or scheme and were merely descriptive and without reflection. The students expressed their understanding of the principles behind the experiments and the artistic practices. The second category of analysis, argumentation, while still not considered as reflection, implies an understanding of either the scientific and artistic concepts or the experiments behind them. The students might explicate the relationships between experiments and the real world. During argumentation, the experimentation is not related to personal learning or personal competences. This corresponds to stage 2. The third category, reflection, is linked to stage 3. At this stage, the students' comments are closely linked to the learning process, i.e., the student presents a sense of belonging and competence. The student is able to suggest high levels of reasoning which includes the organization and development of some of the experiments through a process of reflection in which the experiments were discussed in relation to what was being taught. These were also personal insights going beyond theory, where the students critically and reflectively analyzed all the learning. The fourth category, critical reflection, is linked to stage 4 and implies undergoing a transformation of perspective because the students can now propose areas of application for the concepts from the scientific experiments, or manifest the competences learned cooperatively. The students describe all the processes by employing their own arguments, using significant motivating contextualization, mainly on reflecting on the qualities of science and dance, formulating direct questions derived from the experiments, and creating role models to explain the experiments. The students then transferred the physical parameters into creative and inclusive modes of physical education.

Table 3 presents the classification of primary school students' comments corresponding to the students' reflections for both the science and dance education domains. Units are categorized in terms of the reflective levels of description, argumentation, reflection and critical reflection. Students individualized the knowledge through the transformation of scientific and artistic experiences. They were able to assign the relevant parameters such as force, axes, rotation, mass, etc., to each experience. Students also expressed reflective observation by conceptualizing concepts or acknowledging the attitudes and feelings that were evoked. Some students considered that the experiences had provided a way to dually learn the scientific and artistic contents. In some cases, action was reinforced by the competences and the principles that lay behind them and, therefore, generated the dialogical process between thinking and doing. In addition, students expressed initial understanding of the phenomena of complex systems such as the rotation of the Earth, the basics of sea waves, the movement of some animals and/or the rotation around axes. The understanding of complex systems was intermingled with the appreciation that some knowledge and methods come from both scientific and artistic disciplines, such as, for example, the rotation of systems and bodies around multiple axes.

### 2.4. Statistical Analysis

The comments obtained from the students were analyzed in terms of the degree of reflection following a numerical scale for each classification (description, argumentation, reflection and critical reflection [45]); therefore, this study presents a quantitative analysis on levels of reflections. The number assigned to each level of reflection was quantified by the number of comments obtained in each category for each classification [9,10]. When no comment was made for a certain category, a zero was assigned [9,10]. The database was entered onto an SPSS 21® software spreadsheet, and subsequently analyzed with the same software. Data were first tested for homogeneity and normality. Although some of the datasets fulfilled Levene's test for homogeneity, none of them fulfilled the Shapiro–Wilk test for normality [9,10]. With this consideration, and taking into account that all datasets had 30 observations (i.e., all five observations above), a Kruskal–Wallis test was considered. In all cases, the degrees of freedom were (df = 2), leading to a critical H of Kruskal–Wallis of 5.991 (the Chi-square for df = 2). Therefore, differences were expected to be significant for H > 5.991. In addition, a post-hoc pairwise comparison between courses was made based on the Mann–Whitney U test. The effect size was also reported in the analysis. To calculate the effect size, the value of r is reported, with $r = |Z|/\sqrt{n}$, where n is the total number of observations in the pairwise comparison and |Z| is the absolute value of the Z-score of the Mann–Whitney U test.

## 3. Results

For the analysis of the degree of reflection, no significant differences were found between the courses (K-7, -9 and -11) for the dimensions of analysis corresponding to description, argumentation or critical reflection (Table 4). However, a significant difference for reflection was found between the courses. The pairwise comparison between courses revealed that differences were significant between the first-year and both the third- and fifth-year courses for the reflection category. In addition, a significant difference was found between the first- and third-year courses at the category of description and between the third- and fifth-year courses at the category of critical reflection (Table 4). The mean values were high for description for students in the first and third year, for reflection for students in the first year, and for critical reflection for students in the third and fifth year (Table 4). According to the Cohen's criteria, the effect size was found to be small (r < 0.2) in most of the cases (Table 4). Only some calculated r presented moderate effect size (0.2 < r < 0.5, Table 4).

**Table 4.** Kruskal–Wallis test results for the degree of reflection: Description, Argumentation, Reflection and Critical Reflection, with the degrees of freedom (df), H-value and *p*-value. Results of the *p*-value for the pairwise comparison between courses for each degree of reflection are presented. In parentheses, the value of r (related to the effect size) has been included. The mean and standard deviation for each reflection level and for each course are presented at the bottom of the table. For all the values, * denotes a 95% confidence (in bold) in the analysis and ** a 99% confidence (in bold).

| | Description | Argumentation | Reflection | Critical Reflection |
|---|---|---|---|---|
| df | 2 | 2 | 2 | 2 |
| Kruskal–Wallis H | 5.217 | 2.552 | 9.698 | 1.838 |
| *p*-value | 0.074 | 0.279 | **0.008 ** ** | 0.399 |
| Pairwise Comparison | | | | |
| First-year vs. third-year | **0.019 * (0.13)** | 0.587(0.07) | **0.009 ** (0.34)** | 0.167(0.18) |
| First-year vs. fifth-year | 0.230(0.16) | 0.294(0.14) | **0.007 ** (0.35)** | 0.367(0.12) |
| Third-year vs. fifth-year | 0.315(0.30) | 0.125(0.20) | 0.609(0.07) | **0.035 * (0.15)** |
| Mean and Standard Deviation | | | | |
| First-year | 0.93 ± 0.74 | 0.37 ± 0.49 | 1.23 ± 1.01 | 0.53 ± 0.68 |
| Third-year | 0.87 ± 0.63 | 0.300 ± 0.47 | 0.60 ± 0.62 | 0.97 ± 1.10 |
| Fifth-year | 0.50 ± 0.57 | 0.570 ± 0.68 | 0.60 ± 0.86 | 1.16 ± 0.67 |

## 4. Discussion and Conclusions

The question of whether STEAM education can encourage primary school students to reflect on scientific reasoning and critical thinking has provided some results in which cross-disciplinary instructional interventions, that include the arts, can be fully developed through interdisciplinary approaches across domains [47–49]. Concerns regarding the development of scientific reasoning tend to focus primarily on students pursuing concepts in science, technology, engineering, and/or mathematics (STEM) since scientific reasoning has been given paramount importance thanks to the ever-changing paradigms in the real world that demand deep, structural changes across all sectors in society [50,51]. The application of STEAM approaches in primary school classes was found to produce significant reflection concerning both the science and dance (arts) experiments, with reflection not only focusing on the intake of specific knowledge, but also on an increasing sense of competence readiness, and perception of modes of cooperation as individual responsibility and promotive interaction. The promotion of STEAM approaches in experiential settings is recognized to foster a myriad of teachers' reflections on competences, attitudes and emotions [52]. The participation of the primary school students in cooperative and reflective modes of learning enhanced social relationships between their peers and individual involvement through an individual's inner desire to participate in the scientific experiments and dance activities. Involvement, then, is seen as an inner competence that may be vehiculated through group interactions [53,54].

The main differences (in substantial values) were found in relation to critical reflection, the highest category in the process of reflection [5,15]. Critical reflection implied fifth-year students underwent a perspective of transforming learning because some of them were able to contextualize scientific concepts in the real world or manifested a sense of competence mainly within the framework of cooperation. Students described scientific concepts and their translation into body movement by employing their own arguments, using significant motivating examples, and mostly creating original models to physically interpret the concepts and their qualities behind the experiments. The fifth-year students were able to transfer knowledge into creative and inclusive modes of arts education [55,56]. At the level of reflecting on the experiences, the pairwise comparison between the students defined an important difference between the first-year students and both the third-year and fifth-year students, which is interpreted as a consequence of the cognitive differences of the natural evolutionary process they are in.

It would be logical to argue that the first-year students are in the process of developing operational thinking and that their psychological characteristics have not yet solidified the milestones of this stage of cognitive development. Thus, it is reasonable to assume that the first-year students still maintain a centrist and egocentric perspective, which undoubtedly weakens their path towards critical reflection. In the same vein, the higher assessment on critical reflection from the 5th-year students can be understood as approaching another level of more abstract thought, which undoubtedly allowed for a greater application and transposition of knowledge across the disciplines. Therefore, as reflection is an age-dependent constructive process, the primary school students present different levels of competence. Reflection is based on the capacity of students to construct knowledge around successive cyclical critical thinking and deep analysis [5,35,36], and this was accomplished more in the case of the 5th-year students. In contrast, for the first-year students', description was an issue. For first-year students, primary school teachers will need to create a normative framework of cooperation around experimentation and reflection at the end of each experiment as the students might be struggling with the process of reversibility and reflecting on the process of the operation of the group at an initial egocentric level [55]. If teachers intend to transform students' learning, the instructional approaches must include not only cognitive processes but also introspective inquiring into attitudes and competences, with teachers emphasizing all the aspects of education in order to engage students in critical conversation [47,57]. The experiential activities showed that a critical point that should be considered when developing STEAM activities, is the cyclic process of continuous experimentation [35,36,42] around science and around the inter potential of the body and interrelationships as well. Although Abdulwahed and Nagy [42] postulated that poor learning might be inherent in the laboratory due to insufficient activation of the prehension dimension of Kolb's cycle, the use of continuous reflective experimentation in STEAM activities, where knowledge is cross-referenced in scientific and artistic practices, may influence this aspect. Not only this, we found that STEAM activities may promote intrapersonal skills, reformulate beliefs, attitudes and competences towards understanding our complex world, not only in the scientific domains but also in the social one.

In that sense, this study has proved that when cooperating through sciences and arts, higher levels of reflections are attained by the primary school students, i.e., a learning outcome that is acquired through individual and group interaction. Students might differ in their learning styles and recognizing this is the first stage in raising students' awareness of possible alternative approaches [58]. For example, students developed higher levels of motor skills, including a better knowledge of the capacity of the body to perform precise and complex personal and group movements [55]. During the experimentation with the body, the primary school students understood fundamental dimensions and their qualities of space, equilibrium, scales of time, laterality, synchronization, balance, tension, etc. This implies a full recognition of a changing paradigm in physical education in which the consideration of movement as a language includes an ontological and holistic approach from the teacher that fosters consciousness, centeredness and transformation [59].

In addition, this research proves that STEAM educational processes may promote creativity and critical thinking not only concerning concepts, but also attitudes towards either the arts or the sciences [8,16,29]. Cross-educational approaches tend to search for contextualized questions and their solutions, by combining both scientific and artistic competences towards solution solving [2,8]. Developing science through the arts has been found to develop critical thinking through creativity [60]. This implies an educational approach that is centered on students' individual learning, with them being actively engaged in the process of individual and group learning to construct new knowledge by themselves [4,15,33].

The analysis of the 1st-, 3rd- and 5th-year primary school students' reflective narratives showed that creativity was an indispensable capacity and resource in developing their personal competences. As stated by Pawlak [61], the most powerful tools to stimulate a creative society include creative education, a stimulating environment, and multidisciplinary work teams. This includes, first, promoting attitudes towards observation, perception, and understanding, which deeply rely on the first dimension of experiential learning by promoting grounded experiences [35,36]; second, encouraging personal initiatives such as spontaneity, curiosity, autonomy, which are engrained in the way each student approaches the experience in question; third, stimulating the imaginative capacity of intuition, association, and contextualization, which are the bases of abstract conceptualization, i.e., students understanding the experience [61]. However, the transformation of learning is produced when active experimentation is promoted and assessed, which is the final step of reflective learning [1,4].

All in all, this study highlights the conditional bases to promote STEAM education in primary schools, where critical learning and creativity emerge through students' experiences. This study addresses the fact that, to develop strategic competences, primary education must approach critical learning and creativity by developing: (i) an interdisciplinary educational approach that deals with common competences, (ii) multi-literacy between domains of learning involving an awareness of grounding knowledge, (iii) the need for multidisciplinary learning concepts favoring synergies for knowledge, and (iv) professional teaching development that enhances transformative and constructive pedagogies which state that students' learning is a continuous constructive active process of sharing knowledge, through cyclical experimentation and abstraction.

## 5. Limitation of the Study

This study relies on quantitative analysis structured into four levels of reflection based on coding carried out previously by the researchers concerning the primary school students' perceptions. Assigning students' perceptions to a specific level has been performed by the researchers through a protocol that is exploratory in nature. The primary school students produced reflections in the group processing that took place at the end of the six experiments. Therefore, since critical reflection is fostered through successive cycles of reflection, the results might be biased since more students' perceptions were categorized in the critical reflection level, for the last experiments. The analysis did not use a program to categorize the students' speech perceptions, which might limit the process of their categorization.

This study is also limited in obtaining results on the understanding of scientific experiments and dance experimentation since some of the parameters were new in nature, especially for the first-year students, for which the initial reflection on contextualization was weak. In addition, the students were not used to working in interdisciplinary domains or in the processes of communicating their reflection(s) in a group process. This fact might also bias the results towards low levels of reflection, given that some students might have been reluctant to communicate any critical perceptions of their personal experiences.

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