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Integrated STEAM Education for Students' Creativity Development

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Abstract: This study aims to explore how a learning sequence designed with an Integrated STEAM Education perspective (iSTEAM) contributes to students' levels of creativity. The participants in this study were students from 9th and 10th grade with ages between 14 and 16 years old. Students were challenged to produce a soundtrack for an animation video. This was achieved by building artifacts and using the phenomena of physics under study (mechanical energy) to produce sound effects. These were later digitally recorded and assembled to build the video's soundtrack. This research work contributes to addressing the importance of STEAM education integration and of digital competence in developing students' creativity in problem solving.

Keywords: STEAM education; STEAM integration; creativity development; digital competence; problem solving

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1. Introduction

As the 21st century advances, an increase in challenges associated with the sustainability of the planet and the advancement of technology is expected. This implies a significant growth of professions in areas associated with sciences, mathematics, engineering, and technology (e.g., [1–3]). To be able to find solutions to those challenges, qualified professionals in these areas will be required. These professionals will be required to use acquired skills and attitudes (as students, citizens, and professionals), such as the resolution of multidisciplinary problems, critical thinking, collaboration, and creativity (e.g., [2,3]). No less important is the aim that even citizens who do not occupy these professions be scientifically literate, so that they can respond as active citizens to these challenges [4]. Guiding documents from different countries reinforce the importance of developing STEM (Science, Technology, Engineering, and Mathematics) areas in education and investment [1,5].

STEM education is presented by several authors with various interpretations, from which STEAM (Science, Technology, Engineering, Arts, and Mathematics) education derives. The term STEAM Education will be used when referring specifically to the inclusion of the "A" of arts, and the term iSTEAM when referring specifically to the integration of the five disciplines [6–8]. Quigley [8] defined iSTEAM education as a transdisciplinary approach that aims to solve real-world problems. For other authors, iSTEAM is viewed as a way to better blend the different disciplines so that students can develop specific skills and attitudes, such as creativity, critical thinking, and an innovative mindset [6,9].

Creativity is a skill that cuts across several disciplines, having a prominent and pertinent role in the context of STEAM Education [9]. There is a shortage of studies that correlate STEAM (and iSTEAM) with creativity development [7]. Furthermore, the association of STEAM education with digital competences is scarce and even more so if we exclude programming as a digital competence, or visual arts/design as the art included in STEAM activities [10]. Taking these considerations into account, this study aims to shed light on students' creativity development while performing iSTEAM tasks that involved production, digital recording, and assembly of sound effects to produce a video soundtrack. The sound effects were created using physical phenomena associated with mechanical energy.

Specifically, our study aimed to understand the effect of iSTEAM education on the development of competences associated with creativity. Since these tasks involve the use and development of digital competences as well, we aimed also to understand if the latter could also contribute to creativity development by students. Therefore, the following research question (RQ) guided the study:

RQ: Can iSTEAM education didactic tasks contribute to student levels of creativity while using digital competences?

Considering the aim of this work, iSTEAM education and creativity will be explored in the following subsections.

1.1. Integrated STEAM Education

STEAM education is based on the intention of inserting "A" for Arts into STEM approaches, as first described by Yakman [11]. This author suggests the model STE@M as a framework that implies an integrative and a holistic view regarding lifelong learning, where essential elements of the arts can become related to the STEM disciplines. For Yakman, the inclusion (and integration) of the fine, musical, and manual arts in this model goes further than just product aesthetics and includes the liberal arts (e.g., humanities or social studies). In this model, this inclusion is performed by connecting the different subjects through interdisciplinary approaches. In doing so, teachers are not expected to become experts in all fields, but to acknowledge where their subject meets other fields. That is, according to Yakman, knowing where the connections are within the different fields is what education paradigms usually leave out and what the STE@M framework helps to deepen.

The art disciplines involved in STEAM can be diverse, ranging from fine arts, design, music, and dance, to dramaturgy [11]. It is worth noting that in all these disciplines, creativity is an inherent competence, and the latter is none other than one of the most important competencies of the 21st century [9,12]. These authors and others [13] also highlight the possibilities and importance for science education of including in the "A" the humanistic or social disciplines (alongside with the artistic disciplines). The derivation from STEM education implies that the inclusion of "A" raises the same questions associated with cumulative or integrative models described for STEM education [14]. Some argue that it would not be necessary to add the "A", given that the scope of STEM tasks would already include the use of artistic disciplines [8,13] and the question that arises is whether art disciplines, in STEAM education, can be more than just creating a prototype with a good design or that is aesthetically appealing, or whether it is in fact possible to bring advantages of the "Nature of Arts" to the STEAM tasks in science education [9]. Boy raises yet another issue: "Arts and Engineering are typically opposed, but it takes technical competence to be an artist, and artistic skills to be a great technician" [9]. As such, STEAM education plays a distinctive role, since the nature of the arts can improve the discovery and development of solutions to problems and provide a form of open thinking and knowledge that is associated with subjectivity and divergent thinking, in contrast to scientific objectivity and convergent thinking [15].

Therefore, it can then be suggested that STEAM education aims to enhance and develop the creativity inherent to the arts to enrich STEM education, maintaining the focus on student-centered learning, in which students investigate, communicate, and solve problems [8]. Quigley and Herro also find that this approach enables the curriculum to be extended beyond technical abilities by incorporating creativity and considering cultural and social contexts, which then promotes a more engaging and enriched learning experience. Therefore, these authors claim that STEAM education is a more effective methodology for addressing problems and finding solutions [8]. Furthermore, iSTEAM education can also potentiate students' curiosity about natural phenomena [16] and therefore improve attitudes toward scientific subjects. In its turn, this could result in students who are motivated and interested in science [17].

Divergent views regarding the definition of STEAM education are mainly based on the differences in the "weight" that the different five disciplines can have. While Yakman

and Lee [18] view STEAM education as "Science and Technology, interpreted through Engineering and the Arts, all based in the language of Mathematics" (p. 1074), other authors perceive STEAM education as an effective interdisciplinary or transdisciplinary approach to solving real-world problems [19]. Other questions arise in terms of how the integration of the various areas can be achieved, and the iSTEAM upgrade from the additive or cumulative model would have to ensure the development of diverse competencies as well as knowledge construction. In this sense Ortiz-Revilla et al. [20] developed a model for iSTEAM that can enable these achievements and provides detailed information to aid in understanding the process of design, implementation, and evaluation of an iSTEAM didactic sequence. Here, the aim is to enhance the development of students' skills with the use of active methodologies (e.g., inquiry-based learning) in collaborative work and with a student-centered approach. This is theoretically supported by an epistemological, psychological, and didactic axis. The first relates to the significance of the teaching–learning process as an ongoing problem-solving exercise. The psychological axis highlights the importance of creating a panoply of situations, allowing students to engage with a range of consistent elements, develop and confirm mental frameworks, and achieve a comprehensive understanding or expertise in the conceptual domain associated with the subject. Finally, the didactic axis emphasizes the effectiveness of the objective–obstacle concept, serving as method for choosing objectives in an educational sequence that is centered on overcoming representations. It also serves as a tool to monitor and adjust didactic interventions, helping educators to understand what students articulate and execute [20,21].

1.2. Creativity Development in STEAM Education

The development of creativity in students, which can be enhanced by the "A" of arts in STEAM education, has been the subject of several studies. Some authors have focused on defining and systematizing creativity. For example, "Big C/little c", where "Big C" refers to the creativity revealed by recognized artists or scientists while "little c" is associated with problem solving by ordinary people [22]. Moreover, this is demonstrated in the distinction between "Act" and "Flow". In the first case, "Act" refers to the cognitive process associated with active and conscious thinking, which can be trained and taught. "Flow" monitors typical elements of an individual experience associated with motivation when carrying out a creative activity in a school context. Other authors also added the dichotomy between "mini-c" and "pro-c", distinguishing the creativity to solve everyday problems from creative expression in the exercise of a profession, respectively [22]. On the other hand, others state that this excessive dichotomization can cause problems in the more conceptual definition of creativity [22]. Several studies have also been developed regarding ways to measure creativity. Some tests focused more on evaluating the student's profile, context, or personality. Some examples are: "Adjective Check List", "Domino Creative Scale" [23], and "Group Inventor for Finding Creative Talent" [23]. However, these scales are more descriptive of the student in terms of their choice of curriculum (e.g., attended artistic subjects or not), or if students are described, by their teachers, as creative students or not, etc. Another test described is the "Creative Reasoning Test" [23], wherein creativity is monitored in solving problems in the form of riddles. Even though in the 1980s/90s the focus was on defining creativity, the authors already referred to the complexity of defining it and anticipated the importance of developing it in students in the 21st century. In other words, at that time there was already agreement between authors that creativity was an essential skill for problem solving.

Currently, there are major concerns at a global level regarding the promotion of creativity in students, combined with mental flexibility and motivation for experimentation. In this sense, creativity is considered one of the most important skills to develop in students in the 21st century, together with communication, collaboration in teamwork, and critical thinking [24]. Recent studies have focused on teachers' views on creativity and its development in students. Some report a more negative attitude on the part of teachers towards a type of creative student who may not always have the most appropriate behavior in the

classroom [25]. This author also states that teachers refer to creative students as imaginative and unique, and they often make this association with their artistic abilities [25]. Furthermore, it was observed that most teachers considered that creativity is rare in students, but they also mentioned that it could be developed. Although creativity is recognized as important, it is often relegated to a secondary plan by educational agents when there are time constraints, extensive curricula, etc. [25]. Alongside having time to be creative in the classroom, students also need a favorable classroom environment [26,27]. These authors additionally state that self-confidence and the "courage to take risks" in group work are also important.

The inclusion of the arts and humanities in an activity can then promote more elaborate, creative, and empathetic thoughts in students. These can, in turn, contribute to the development of essential competences associated with teamwork, communication, trust, autonomy, and motivation [9,13]. No less important are the exploratory tools associated with the nature and didactics of the arts in which the development of students' creativity is well explored [9]. Creativity is a skill within the reach of any individual and not just for those who develop skills in artistic areas and, like other skills, it can be developed [28]. In this sense, Cropley [23] and Thuneberg, Salmi, and Bogner [29] selected criteria associated with monitoring the development of creativity in students. These criteria were divided into two subscales, "Act" and "Flow", where the first covers conscious and trainable cognitive processes, and the second covers elements of flow experiences and a mental state of creativity. Some examples for "Act" were as follows: incorporation of an already-used solution in a new way; bringing together unrelated concepts to create an idea/solution; creating a connection between the proposed problem and a related situation; approaching the problem from different perspectives to find a solution; requesting help from other people (classmates or teacher) to help solve a problem; and attempting to think/imagine several solutions to solve a problem (not immediately accepting the first solution). Regarding "Flow", the criteria range from immersion in problem solving and a feeling of effortless work to proactivity and communication of ideas.

2. Materials and Methods

2.1. Participants and Context

This study involved the participation of forty-nine students with ages between 14 and 16 years old. From these, twenty-two were female students. The students attend schools in the Lisbon district (Portugal) and were from a favorable socioeconomic context (no students with state grants). These students performed iSTEAM activities in the context of learning about "Energy" domains (e.g., energy forms and transformations, free fall, inclined plane, etc.) in physics class from two different and consecutive grade levels.

The related tasks were performed during consecutive classes (of 45 or 90 min) for a total time of 8 to 10 h. Each group had extra asynchronous time to complete written registers and to listen and select the audio records. Synchronous time in a ZOOM remote session was also provided to each group to perform the assembly of the recordings with the video images (ranging from 20 to 40 min by each group in small group sessions).

Specifically, the iSTEAM tasks comprised three distinct phases: (a) introduction and exploratory phase; (b) construction of the final artifact(s); (c) digital recording and assembly. In the initial phase, students were introduced to the main goal of the tasks: to produce a soundtrack for a video using physical phenomena to obtain sound effects. Additionally, students started to explore different variables in small experiments (release height, falling material mass or type, impact surface, etc.) and made initial recordings and measures using their own smartphones. During the second phase, students planned, tested, and adjusted artifact(s) that were able to perform the intended sound effects. This facilitated the engagement of students in problem solving and inquiry-based activities integrating engineering and design. In the third phase (recording and assembly), students used their final artifact(s) to digitally record the intended sound effects and assemble them with the video images. The recording of the sound effects by the students was during class, but the

selection and placement of the recordings was performed remotely, asynchronously and synchronously (ZOOM remote small group class).

2.2. I-STEAM Activity and Curricular Context

The developed activities were focused on the topic "Energy and its conservation" and were designed using the concept of iSTEAM education, where the integration of the five disciplines involved was intended. The students worked in groups, with nine groups of 4 elements (1A, 1B, 1C, 2A, 1E, 1F, 1G, 2E, and 2F) except for one group of 3 elements (2G) and two groups of 5 elements (2B and 2C), for a total of twelve groups. At the level of gender distribution, each group contained at least one female and one male element, except for group 2E, with only female elements. The students' work groups were chosen, so that they were heterogeneous groups according to different teachers from the different school disciplines involved.

A summary of the main stages of the activity, as well as the curricular contents according to the learning goals predicted in the Portuguese standards, are summarized in Appendix A (Table A1). These tasks also allowed for the development of other skills and attitudes foreseen in the Portuguese standards, such as collaborative work, being proactive and autonomous, creativity, and critical thinking, as well as transversal skills associated with the students' procedural knowledge (development of procedures, schemes, problem solving, and rigor, among others). Considering the guiding documents of the Portuguese curriculum, this activity was aimed at students attending the 9th and 10th grade. This activity aligns with the previously described model for iSTEAM [20,21]: the development of students' competences and knowledge is grounded in the utilization of student-centered pedagogical methodologies, such as inquiry-based learning and problem-based learning. As such, students were required to work collaboratively to solve the presented problems and subsequent problems encountered.

Briefly, the tasks developed with students had the common objective of producing the soundtrack for an animated video "How do you Land on Mars" by NASA [30], or for a video about the Portuguese "25th of April revolution", produced in history class. The video narration or additional voice effects were developed and recorded in Portuguese class. To construct the artifacts that allowed for the sound effects' production for the soundtrack, students studied and explored three physical phenomena (free fall, movement on an inclined plane, and vertical fall with bounce).

It was pertinent to explore the energy domain in these activities, given the physics curriculum of the participant students, and because there is an alternative conception in the energy domain associated with the "loss of energy" [31,32] instead of its dissipation (through transformation into a form of energy that is not useful). In this sense, working with students on the concept of sound energy, as a form of energy that can be either dissipated or useful energy depending on the objective, while they are exploring sound effects, was very relevant to us.

The classes were prepared according to the model provided by Rodback et al. [33] The plans for each individual class or each block of two classes (corresponding to a task) were organized in three main moments: introduction/contextualization of the task, completion of the task, and final synthesis.

2.3. Research Design

This is a qualitative and interpretative study which included data collection from participant observation, namely using field notes that were written at the end of each class, when the iSTEAM tasks were performed by students and later transcribed and categorized. That is, the participant observer audio recorded, orally, the field notes immediately after each class, and these were later transcribed and completed with the observations of a second observer. Written registers of students were also taken, as well as photographic/video registers during activity completion. During the activities, i.e., during classes, the first author took photographs and videos of the artifacts and of the screenshots of the video

editing program (DaVinci Resolve). Each student also performed written records during activities (drawing schemes, writing procedures, observations, and reflections) that were collected by the teacher at the end of each task.

Different types of qualitative instruments were used, for example, the participant observation was complemented with field notes recorded on audio support right after each class. Data were also cross-referenced with observations of the second observer and with the videos of the students working with the artifacts and recording the sound effects, with students' written records associated with the written completion of tasks, and with the self-assessment carried out by the students at the end of the project.

All field note recordings were transcribed by the first author for subsequent analysis. Therefore, after reading the transcriptions, the first author proceeded with their categorization. After that, based on the categories that emerged from the data analysis, the second author analyzed the codes and created other codes if necessary. The two researchers compared their codes and discussed a consensus coding scheme. Subsequently, the data analysis involved developing a rubric to score according to these observations.

The analysis of these results is based on a selection of criteria associated with monitoring the development of creativity in students already described in the literature [23,29]. According to these authors, these dimensions are divided in "Act" and "Flow", previously described as follows:

- "Act"—incorporation of an already-used solution in a new way; bringing together unrelated concepts to create an idea/solution; creating a connection between the proposed problem and a related situation; approaching the problem from different perspectives to find a solution; attempting to think/imagine several solutions to solve a problem (not immediately accepting the first solution);
- "Flow"—immersion in problem solving; feeling of effortless work; proactivity and communication of ideas.

The rubric used in this study was then built upon with four components of creativity evaluation (I, II (a and b), III, and IV) and adapted to accommodate the data that were related to the topic under study (Table 1). The second author, along with other experts in science education, reviewed the rubrics for content validity.

Table 1. Evidence dimension to assess students' creativity development and assessment levels.

Evidence Dimension	Insufficient	Sufficient	Good	Excellent
I: Incorporation of a solution previously used in a new way; approaching the problem from different perspectives to find a solution.	The students remained in the initial structure of the artifact, not exploring different options.	The students remained in the initial structure of the artifact but tested some options.	The students changed their initial artifact to match what was intended, with some exploration of the different options.	The students changed their initial artifact to match what was intended, exploring diverse options in detail.
IIa (in artifact construction): Creation of a connection between the proposed problem and a related situation; attempting to think/imagine several solutions to solve a problem (not immediately accepting the 1st solution); combining unrelated concepts to create an idea/solution.	The students were unable to use the physics phenomena under study to solve the proposed problems.	The students were able to use the phenomena of physics under study to solve the proposed problems, but immediately accepted the first solution.	The students were able to use the phenomena of physics under study to solve the proposed problems, testing several solutions.	The students were able to use the phenomena of physics under study to solve the proposed problems, testing several solutions, obtaining diversity, and overcoming relevant difficulties in relation to the desired sound effects.

Table 1. *Cont.*

Evidence Dimension	Insufficient	Sufficient	Good	Excellent
IIb (in digital assembly of the soundtrack of the video): Creation of a connection between the proposed problem and a related situation; attempting to think/imagine several solutions to solve a problem (not immediately accepting the 1st solution); combining unrelated concepts to create an idea/solution.	The students were unable to listen and select coherent and pertinent sound effects from the audio files for the intended parts of the video.	The students were able to listen and select coherent and pertinent sound effects from the audio files for the intended parts of the video but were satisfied with their first chosen option of placement and did not request additional digital alterations.	The students were able to listen and select the sound effects from the audio files for the intended parts of the video, and after testing their first chosen option of placement, chose different placements, duplication, overlaps, or requested additional digital alterations.	The students were able to listen and select the sound effects from the audio files for the intended parts of the video, and after testing their first chosen option of placement, chose different placements, duplication, overlaps, requested additional digital alterations and still wanted to improve the artifact construction to produce and record improved sound effects.
III: Immersion in the resolution of the problem; feeling of effortless work.	The students were not committed to solving the problems.	The students showed commitment to solving the problems but perceived the passage of class time.	The students showed commitment to solving the problems, not noticing the passage of class time.	The students showed commitment to solving the problems, not noticing the passage of class time. The students worked on the construction of the artifact outside of school time.
IV: Proactivity and communication of ideas to peers.	Students do not present relevant ideas, or refuse to work even when oriented in that direction.	Students present some relevant ideas, working only when oriented in that direction.	Students present useful and relevant ideas, working actively, yet with poor time management.	Students present useful and relevant ideas, actively working in the time available and encouraging the participation of all for the application of their ideas.

Based on the rubric, observation, students' written records, and photograph/video records, the first author primarily analyzed the data and the second author reviewed them to reach a consensus on scoring for each of its components on a scale from "Insufficient" to "Excellent." Several examples illustrating how the data were analyzed will be presented in the results.

To facilitate analysis, since each group had approximately 20 s of soundtrack of each video, the groups of each shift are identified by the shift number and by A, B, C, E, F, and G. These last six alphabetical identifiers correspond to the parts of the video that were assigned to each of the 3 groups in their shift. In other words, in the case of the two NASA videos, one for each shift lasting 1 min each, we have the initial part (A), the intermediate part (B), and the final part (C). In the case of the "25th of April revolution" video, one for the whole class which was 2 min long, the sequential distribution of groups was 1E, 1F, 1G, 2E, 2F, and 2G. All groups were composed of 4 elements, except for group 2B (5 elements), 2C (5 elements), and 2G (3 elements).

3. Results

The work developed by students during iSTEAM tasks went from creating simple to complex artifacts. With the latter, students produced sound effects that could be used in the production of the soundtrack for animated videos lasting between one and two minutes. The three videos with the corresponding soundtrack can be viewed on YouTube, with a correspondence of about 20 s to each group in the following order: 1A, 1B, and 1C (Video S1); 2A, 2B, and 2C (Video S2); and 1E, 1F, 1G, 2E, 2F, and 2G (Video S3).

In addition to the creativity associated with the exploration of sound effects, the students' creativity was also analyzed in the choice of moments in the video at which the sound effect would be placed, regarding the relevance of its visual or scripted context. Although the students made a written record of the time intervals with which each sound effect would be associated, some digital changes were made later at the students' request after viewing the result of the assembly. These changes occurred when students remotely followed the audio files' assembly to the video images, in group by group ZOOM sessions.

The analysis of the data collected through the previously described instruments, in material and methods, allowed for the assessment of students' creativity levels, considering several dimensions in group-based analysis. The results of this analysis are compiled in the graph presented in Figure 1.

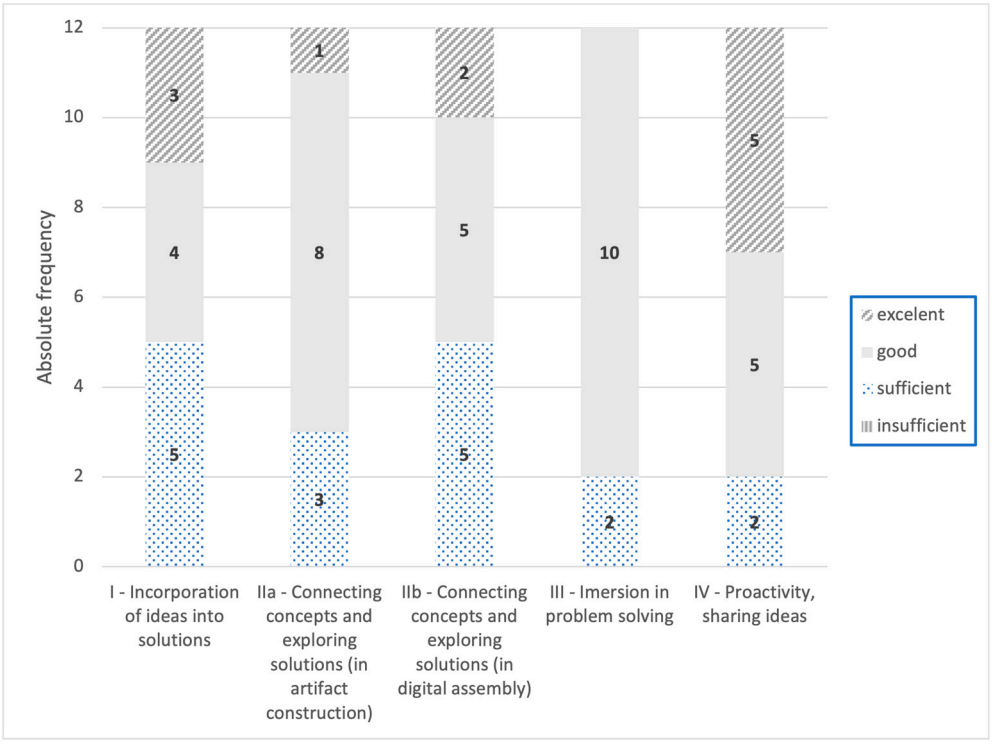


Figure 1. Assessment level obtained by student groups according to the different dimensions of creativity development. Absolute frequency is referred to the number of groups (in a total of 12 groups).

Based on these results, it is possible to observe that the iSTEAM tasks, performed with students in teams, were able to develop their creativity in several dimensions. More specifically, iSTEAM tasks positively influenced the development of creativity in students regarding incorporation of ideas previously used into new solutions or finding solutions by approaching a problem from different perspectives (I). In the latter, a slight majority of groups could achieve good or excellent levels (58%).

While constructing the final artifacts and digitally assembling the soundtrack, the results were also very positive regarding students' ability to connect the proposed problems to a related situation previously experienced, allowing them to explore several solutions and to find new ideas by blending unrelated concepts. For these criteria, 75% (IIa) and 58% (IIb) of groups could obtain a good or an excellent level during final artifact construction and digital assembly, respectively.

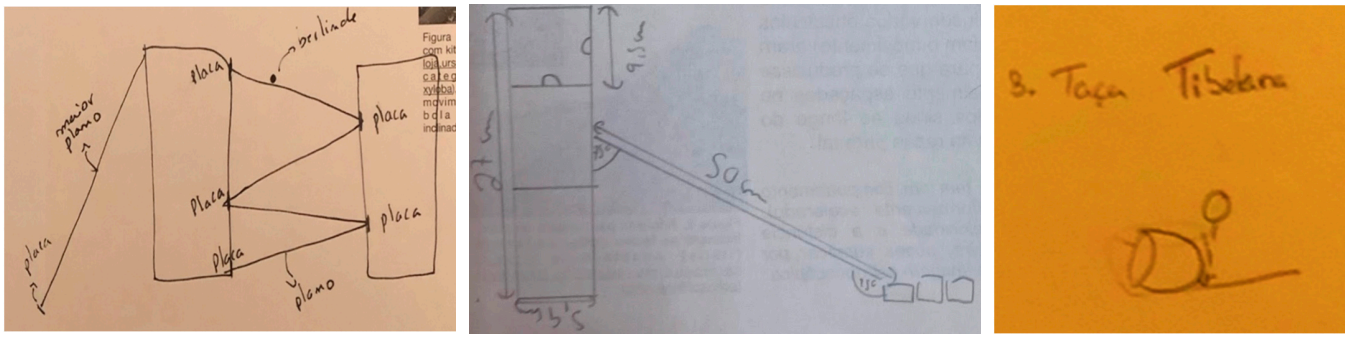
Considering the dimensions more related to the students' motivation (III) and group environment to perform creative work (IV), a more expressive majority of groups, 83%, attained good and excellent levels. These values were obtained while evaluating students'

immersion in problem solving and the observed proactivity and communication during teamwork, respectively.

Each dimension (I–IV) will be hereby analyzed in three subsections, with dimension I analyzed in the first Section 3.1, then dimensions IIa and IIb in the second Section 3.2, and finally dimensions III and IV in the third Section 3.3. In these subsections, a more comprehensive description of the assessment by level that was considered is presented, along with justificative examples for the given scores. For each level of competence, an example associated with the respective group is detailed, and some will be illustrated below from students' written records. Note that this assessment concerns the construction of the final artifacts and the digital recording and assembly of the sound effects produced by the students in the final iSTEAM tasks. The evidence associated with the development of creativity competence, in the initial iSTEAM tasks of introductory nature, were scarcer. Nevertheless, some pertinent examples are presented below (Section 3.3) to provide evidence for a creativity-prone environment.

3.1. Students' Incorporation of Ideas into Solutions

There was a wide variety of artifacts and sound effects produced between the different groups and more specifically by groups 1A, 1B, 2A, 1G, 1E, 2E, and 2F. This was achieved while exploring solutions from different perspectives (exploring materials or other variables) or incorporating solutions in a new way (changing conditions to obtain exactly what was intended). Some examples are presented in Figure 2, wherein students explored different marble positions to obtain different rhythms (Figure 2a), different impact surface material (Figure 2b), or new ways to play a musical instrument, while using the physical phenomena under study (Figure 2c). In the latter, it is even possible to observe evidence of the previously drawn image of an upright Tibetan cup that was then erased and changed for the final inclined position (that then allowed for the typical resonance of this instrument).



(**a**) (**b**) (**c**)

Figure 2. Schemes in students' written registers while exploring and constructing the artifacts to produce sound effects: (**a**) group 1A, the meaning of the Portuguese words from left to right are (metal) plate ("placa"), major plane ("maior plano"), marble ("berlinde"), and plane ("plano"); (**b**) group 2E, although students wrote no legend, at the end the marble fell and bounced into three different metal plates; (**c**) group 2A, the meaning of Portuguese words are Tibetan cup ("Taça Tibetana").

The examples shown from students' written records and the participant observer field notes justify the attributed creativity development levels obtained by the groups in evidence dimension I (Table 2). For example, the enriched exploration of group 2A, which led to the achievement of the Tibetan cup's typical resonance, or of subtle changes in sound effects (by changing rolling surfaces in the inclined plane) allowed them to obtain the excellent level in dimension I (Table 2). The 1E and 1G groups also obtained this level by exploring the simultaneous execution of various sound effects: "1E students were very persistent managing to play a sequential melody with different elements of the group dropping marbles and putting the metal plates under a soft surface to cancel sound effect

from the bounce of the ball". Group 1G also managed to "cancel sound effect from the ball by grabbing the ball by hand just after it impacted the surface". This group, in fact, performed live synchronization of the intended sound effects (Video S3, 0:38), requiring effective teamwork that will be further detailed in Section 3.3.

Table 2. Examples that led to the attribution of the assessment levels to students' creativity regarding dimension I.

Evidence Dimension	Insufficient	Sufficient	Good	Excellent
I: Incorporation of a solution previously used in a new way; approaching the problem from different perspectives to find a solution.	The students remained in the initial structure of the artifact, not exploring different options.	The students remained in the initial structure of the artifact, but tested some options. - Students explored the position and number of marbles (1C and 2C); - Students explored the type of materials used and free-fall height (2B, 1F, 2G).	The students changed their initial artifact to match what was intended, with some exploration of the different options. - Students built an additional inclined plane in order to obtain the desired sound effect (1A); - After the construction of a traditional rain stick, which did not allow for the control of the time interval of the sound effect, the students carried out a new construction using the inclined plane and testing different materials (1B); - The students explored some diversity of timbres, not only in the initial exploration but also later after verifying the result of the initial digital recording (2E and 2F).	The students changed their initial artifact to match what was intended, exploring diverse options in detail. - Students explored different rolling surfaces to obtain different timbres (2A); - Students used the free-fall marble to allow for the sound effect in the Tibetan cup, testing in detail the specific position of the Tibetan cup to obtain this instrument's characteristic resonance (2A); - After the construction of the initial artifact, the students explored timbres with different materials and tested the simultaneous and/or sequential execution (1E and 1G).

The groups 1A, 1B, 2A, 1G, 1E, 2E, and 2F stood out (with good or excellent levels) in dimension I of creativity, therefore they could later select from a good variety of sound effects and produce a coherent, diverse, and enriched soundtrack. This good variety of sound effects was also achieved by other groups that excelled instead in dimension II, as will be detailed in the next section.

3.2. Students' Connection of Concepts and Solution Exploration

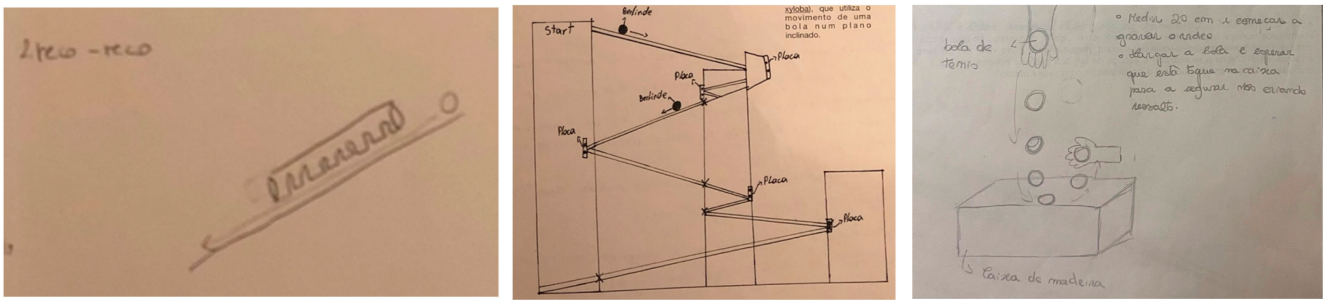
In addition to solving problems associated with the production of sound effects, students had to solve problems using the physical phenomena under study. This led to an enriched level of exploration of different solutions and troubleshooting. This exploration occurred not only during artifact construction (dimension IIa, Table 3) but also during digital assembly (dimension IIb, Table 3). As shown in Table 3, similar to what was observed in dimension I, groups 1A, 1B, 2A, 1G, 1E, 2E, and 2F obtained "good" or "excellent" levels in dimension IIa. On the other hand, groups 1C and 2C excelled in the IIa dimension category even though they did not in dimension I. As for the remaining groups, 2B and 2G could only obtain a good level in the IIb dimension category. The group 1F was the only group that remained at sufficient level, both in dimensions IIa and IIb, as observed previously for dimension I (Section 3.1).

Table 3. Examples that led to the attribution of the assessment levels to students' creativity regarding dimension Iia and Iib.

Evidence Dimension	Insufficient	Sufficient	Good	Excellent
IIa (in artifact construction): Creation of a connection between the proposed problem and a related situation; attempting to think/imagine several solutions to solve a problem (not immediately accepting the first solution); combining unrelated concepts to create an idea/solution.	The students were unable to use the physics phenomena under study to solve the proposed problems.	The students were able to use the phenomena of physics under study to solve the proposed problems, but immediately accepted the first solution. - Limited exploration of the different materials placed in motion in the inclined plane. Such exploration only occurred when it was indicated that the timbre exploration of sounds should first be done physically (2B 2); - Limited experimentation with fall height and time intervals between rebounds in free-fall with rebound (2B 2, 1F, 2G).	The students were able to use the phenomena of physics under study to solve the proposed problems, testing several solutions. - Exploration of the different time intervals in obtaining the sound effects, either by object number or placement (1A, 1B 2, 1C and 2C); - Exploration of timbres and tones of sound when impacting different obstacles (1A, 1C and 2C, 1E, 1G, 2E, 2F).	The students were able to use the phenomena of physics under study to solve the proposed problems, testing several solutions, obtaining diversity, and overcoming relevant difficulties in relation to the desired sound effects. - Use of the free fall of the marble in the Tibetan cup to produce the sound effect, instead of producing the effect in the traditional way of playing that instrument (2A); - Use of a reco-reco laterally increasing the friction in the inclined plane and producing the intended sound effect, instead of producing the effect by playing the instrument in a traditional way (2A).
IIb (in digital assembly of the soundtrack of the video): Creation of a connection between the proposed problem and a related situation; attempting to think/imagine several solutions to solve a problem not immediately accepting the first solution); combining unrelated concepts to create an idea/solution.	The students were unable to listen and select coherent and pertinent sound effects from the audio files for the intended parts of the video.	The students were able to listen and select coherent and pertinent sound effects from the audio files for the intended parts of the video but were satisfied with their first chosen option of placement and did not request additional digital alterations. - Satisfaction with the first placement asynchronously decided. This placement was coherent with the video images (1C, 2A, 2C, 1F, 1G [1]).	The students were able to listen and select coherent and pertinent sound effects from the audio files for the intended parts of the video, and after testing their first chosen option of placement chose different placements, duplication, overlaps, or requested additional digital alterations. - Requested a minor change in reproduction speed so the free fall and bounce would be better synchronized with the images (1B 2); - Requested a pitch change in the sound effect obtained with the rain stick (2B 2); - Presented a pre-organized list previewing repetition of sound effects, previously tested asynchronously in an audio editing tool, but still requested adjustments after seeing the result in video synchronization (1A, 1E, 2G).	The students were able to listen and select coherent and pertinent sound effects from the audio files for the intended parts of the video, and after testing their first chosen option of placement chose different placements, duplication, overlaps, requested additional digital alterations and still wanted to improve the artifact construction to produce improved sound effects and record them. - Unsatisfied with the result of the initial recording (in terms of timbre), students repeated recording of the artifacts, changing some materials and still requested digital alterations such as sound overlap (2E and 2F).

[1] This group performed live overlap in the recording by overlapping the sound effects physically; natural reverberation was also achieved, thus not requiring digital effects. [2] Students were encouraged to physically adjust the artifacts so that the synchronization or timbre was achieved, but digital alteration became an additional option to solve the problem.

Group 2A once again positively stood out, obtaining an excellent level in IIa by overcoming relevant difficulties to produce sound effects with two musical instruments that could not be played in a traditional way to respect the use of the phenomena of physics under study: "[By understanding] that they had to use the phenomena of physics under study, the students did not give up, eventually being able to play the reco-reco using [a marble] movement in the inclined plane." See also Figure 3a and Video S2 in Supplementary Materials at 1:49 in making of. This was a good example of the problems encountered and how the search for their solutions drove students to develop their creativity. Group 2C also overcame a similar type of difficulty for one of the instruments (Video S2 at 2:46 in making of). The 1C group was original in the use of two marbles, dropped at different points of the inclined plane to create repetition of the same sound at different times (Video S1 at 2:22 in making of and Figure 3b).



(**a**) (**b**) (**c**)

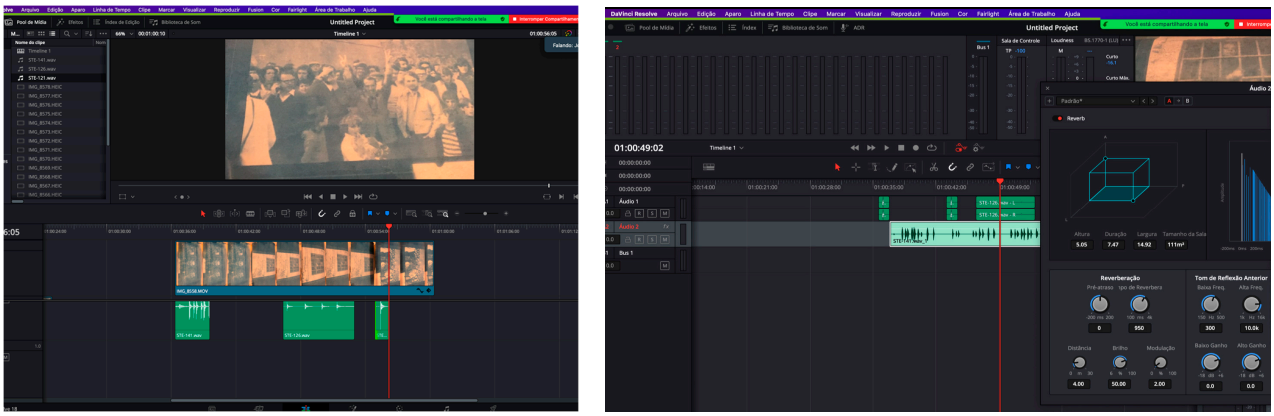
Figure 3. Schemes in students' written registers: (**a**) group 2A, the meaning of Portuguese words are reco-reco ("reco-reco" Brazilian percussion instrument); (**b**) group 1C, the meaning of Portuguese words in the scheme from top to bottom and left to right are marble ("berlinde") and metal plate ("placa"); (**c**) group 2E, the meaning of Portuguese words from top to bottom are tennis ball ("bola de ténis"), wooden box ("caixa de madeira"), the bullet points in the right mean, "measure 20 cm and start recording the video, drop the ball and wait for it to beat the box to then hold it, so that there is no bounce".

It is interesting to note that some groups could improve their level from dimension IIa to dimension IIb (Table 3). In group 2E, in the construction of the artifact (IIa) the level was "good" but a better level of development of creativity was achieved in dimension IIb in digital assembly: "excellent". It is possible to observe in students' written records (Figure 3c) that the artifact was simple (even though students explored diverse fall heights and materials), so students were not satisfied with the result before digital assembly and wanted to add complexity to their sound effect by overlapping sounds. For the same reason this improvement was also achieved by group 2F in the same level difference. As for groups 2B and 2G, the improvement was from level "sufficient" (in dimension category IIa) to "good" (in dimension category IIb).

In the opposite direction were the students from group 1G who decreased their level from "good" in IIa dimension (artifact construction, Table 3) to "sufficient" in IIb dimension (digital assembly, Table 3). As referred to previously in Section 3.1 and in footnote 1 (Table 3), the students from this group developed a natural overlap and reverberation in live recording (Video S3 at 0:43) with synchronization, teamwork, and sound resonance of the different materials explored. Consequently, the students of this group were satisfied with direct digital assembly in the remote ZOOM session. This also happened with group 2A who developed their creativity with an "excellent" exploration level during the construction of the artifact (both in dimensions I and IIa) and, as such, later in the digital assembly they were already satisfied with the result obtained, and therefore did not further digitally explore their recorded sound effects.

On the other hand, groups 1A and 1E maintained the level of "good" in dimensions IIa and IIb, and group 1F maintained the same level of "sufficient". Group 1E presented

a "good" creativity development in the digital editing and assembly of the sound effects by requesting the duplication, changes in position, and reverberation of sound effects, in order to be more coherent with the narrative or even to adjust a melody superimposed in the background during narration (Figure 4).



(**a**) (**b**)

Figure 4. Screenshots of DaVinci Resolve (video editing program) during group 1E digital assembly: (**a**) requested adjustment of sound effect to the video timeline; (**b**) requested digital alteration of the sound (digital reverberation).

As for group 1A, they had already predicted and tested in an audio program, in asynchronous mode, the duplication of sound effects, so they organized a detailed list with the necessary repetitions (Figure 5). As a result, the remote session in the video editing program was more efficient, and more time could be used exploring the assembly with the video timeline and digital sound effects. This organized written register of the recorded sound effects helped students to develop their creativity during the digital montage, as students from this group predicted the repetition of sound effects and their placement along the video timeline. Other groups, such as groups 2C, 2A, and 1E, carried out a similar approach, i.e., they systematized the information regarding the audio files so that the digital montage could be successful, although in a not so detailed and effective form. These types of skills were no longer evidenced in the written records by other groups. However, given that this organization would have to be carried out prior to the digital assembly, the students of these groups gathered the necessary information in asynchronous work prior to the remote group session.

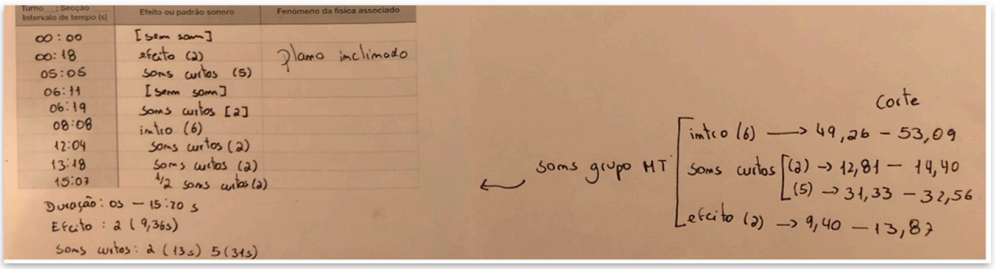
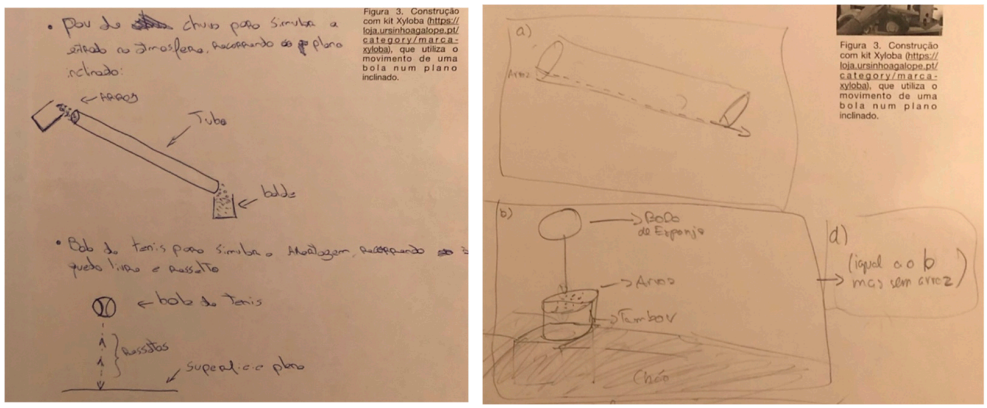


Figure 5. Table list in students' written register from group 1A. The meaning of Portuguese words in the table are, from top to bottom, time interval ("intervalo de tempo"), sound pattern or effect ("efeito ou padrão sonoro"), associated physical phenomena ("fenómeno da física associado"), without sound ("sem som"), effect ("efeito"), short sounds ("sons curtos"), introduction ("intro"), inclined plane ("plano inclinado"), and duration ("duração"). The meaning of Portuguese words on the right side of the diagram are, from top to bottom, cut ("corte") and sounds of group MT ("sons do grupo MT"—group 1A named themselves after the scientist Mária Telkes).

The awareness of students about the possibility of digital alteration of sound effects led groups, such as 2B, to suggest, for the two intended sound effects, that their synchronization and the height of sound (frequency) should be changed digitally, without carrying out a material exploration in the first place: "the students asked if the frequency could be changed digitally at a later stage". Regarding the synchronization of the sound effects, the students of the 1B and 2G groups also "asked if they could record four impacts, and then in the assembly of the audio synchronize them" with the images of the video. This shows, in these groups, an anticipation of the digital tools that they would have at their disposal later. Yet, they were oriented to first obtain the desired sound effect, as directly as possible, in the construction phase of the final artifact.

In fact, the groups 1B and 2B developed a decreased number of artifacts (only two) in the construction phase (Figure 6) and consequently were unhappy with the small diversity of sound effects obtained. Therefore, they requested more digital alterations in terms of timbre and regarding time adjustment or sound reproduction velocity to perfectly synchronize the sound with the image (Video S1, 0:34; Video S2, 0:39; and footnote 2 of Table 3). These requests led both of these groups to attain the level "good" in dimension IIb, yet during artifact construction group 2B explored fewer timbres than group 1B, hence their different level in dimension IIa.



(**a**) (**b**)

Figure 6. Schemes in students' written registers: (**a**) group 1B, the meaning of Portuguese words from left to right are (metal) plate ("placa"), major plane ("plano maior"), marble ("berlinde"), and plane ("plano"); (**b**) group 2B, the meaning of Portuguese words from top to bottom are rice ("arroz"), sponge ball ("bola de esponja"), rice ("arroz"), drum ("tambor"), floor ("chão"), and in the right, equal to b but without the rice ("igual ao b mas sem o arroz").

It is worth noting that the NASA animation video images for section B (e.g., Video S2, from 0:19 to 0:40) were more explicit in terms of requesting specific sound effects, such as rain or fall and bounce. Nevertheless, nothing impaired the students from producing more melodic or rhythmic sound effects, but since the rain sound effect was particularly challenging for the students (in terms of timbre and duration exploration), it was not possible, during the time of the classes, for them to produce other sound effects.

During the soundtrack production and image-video assembly and synchronization, students were required to use and develop their digital competences. More specifically, in the post-production in the ZOOM remote session, students got familiar with audio editing software (Figure 4). Learning the basics of audio editing software allowed students to create new sound effects by layering different sounds and by applying digital effects to the recorded sounds. This required them to develop their problem-solving skills to achieve a pertinent soundtrack by adjusting timeline placement, overlapping sounds, or even reproduction speed (e.g., Video S3; from 0:02 to 0:12).

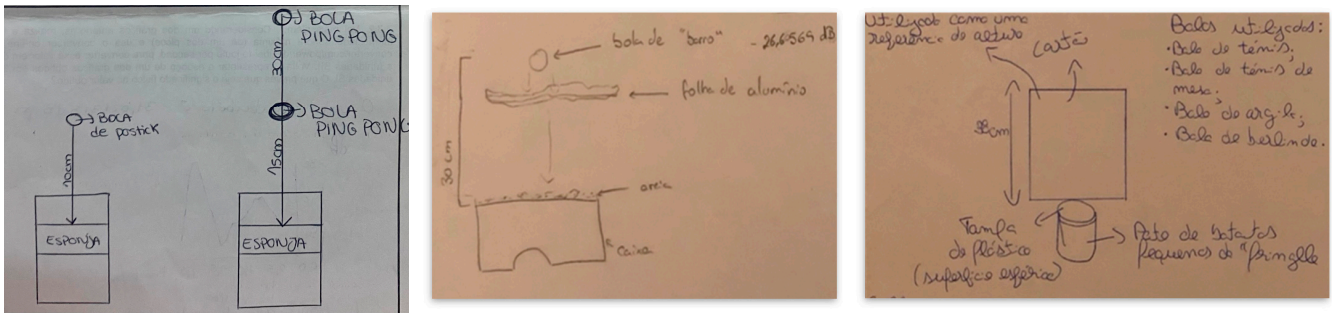
The previously described "Act" dimensions (I and II) addressed creativity levels regarding actual construction of artifacts and production of sound effects and digital assembly

by students. As previously described in materials and methods, the "Flow" dimensions (III and IV) are also important for proper creativity development along with a classroom environment suitable for creativity development. Therefore, we considered it pertinent to address these issues in the next section, where dimensions III and IV are detailed.

3.3. Environment for Creativity Development

As previously described, the evaluation of creativity can be performed regarding the students' activity and the creativity-prone environment in the classroom. With that in mind, the teacher planned sufficient time for the proposed activities, supplied enough materials and only oriented students when asked or when it was strictly necessary. Moreover, students were exposed in the initial tasks to several explorations associated with the fall and bounce or deformation of a ball, or the exploration of relevant historical artifacts. For example, group 1C (Figure 3b, Section 3.1) explored different starting positions of the marbles in the final artifact, and they might have considered this possibility due to the observations made when analyzing an historical artifact in the initial iSTEAM tasks.

Since students were able to freely explore the materials and to get familiar with them in these initial tasks, this might have positively contributed to the evolved exploration that they performed for the construction of the final artifacts, as the same materials were available during the different classes. In Figure 7 is possible to observe some examples of the initial artifacts performed by students in the exploratory classes. For example, the 2F group (Figure 7a) explored a variety of falling surfaces and heights, including the mixture of various materials.



(**a**) (**b**) (**c**)

Figure 7. Schemes in students' written registers: (**a**) group 2F, the meaning of Portuguese words from top to bottom are table tennis ball ("bola ping pong"), patafix adhesive ball ("bola de postick") and sponge ("esponja"); (**b**) group 2A, the meaning of Portuguese words from top to bottom are clay ball ("bola de barro"), aluminum sheet ("folha de alumínio"), sand ("areia"), and box ("caixa"); (**c**) group 2C, the meaning of Portuguese words in the scheme from top to bottom and left to right are used as a height reference, card ("cartão"), plastic cover ("tampa de plástico"), spheric surface ("superfície esférica"), small Pringles pot ("pote de batatas pequenas de pringle(s)"). The meaning of Portuguese words in the caption are from top to bottom, balls used ("bolas usadas"), tennis ball ("bola de ténis"), ping pong ball ("bola de ténis de mesa"), clay ball ("bola de argila"), and marble ("bola de berlinde").

Field notes from the observer also indicated that students started the immersion in the tasks with motivation and enthusiasm and with an exploratory mindset: "when exposed to the [muted NASA animation] video the students were engaged and vocally expressed sound effect possibilities, like a "sh" sound for atmosphere entrance". In the initial iSTEAM tasks, since these occurred soon after the exhibition of the video, or its script, some groups showed evidence of creativity development by exploring the different materials available. For example, group 2A (Figure 7b) tried to create surfaces similar to the surface of Mars, or to simulate the sound effect associated with the entry of the capsule into the atmosphere: "One of the groups even tried to simulate a falling surface similar to the surface of Mars [2A]; it also tried to carry out the (. . .) production of sound in the course of the fall, placing light obstacles such as strips of aluminum foil.". This was also attempted by another group,

2E, that planned the reproduction of effects similar to the sound of gunshots and steps (compatible with a demonstration and police repression present in the script) and, in fact, were able to reproduce those in their final artifact (Figure 3c in Section 3.1, and Video S3, 0:59). These examples suggest that the freer exploration of the materials in the initial tasks had a positive impact in the exploration of the final artifacts, even with limited time.

Furthermore, in Figure 7 it is possible to observe examples that show that from the beginning students were engaged in controlling their variables with the available materials: "students (. . .) used fixed-dimensional structures to define the falling height of the object, such as a piece of cardboard to support the hand that dropped the object (2C) and the forearm itself (2A)".

As an indicator of enough availability of material, roughly half of the material provided remained unused for the final artifacts. Additionally, students could request extra material from the laboratory or bring materials from home. Although the latter was orally referred to by students: "Tomorrow I can bring a furry ball that I have at home", this was not concretized. The majority of students that participated in this study had relevant time-consuming extracurricular activities and did not engage in this project outside the class (except for the asynchronous work to prepare for the ZOOM group sessions). Hence none of the groups achieved "excellent" in dimension III, which would have implied the extra construction of artifacts outside the class, as previously shown in Figure 1. The detailed results of this dimension can be observed in Table 4. Nevertheless, the great majority of groups did obtain level "good" in dimension III regarding their commitment to solving problems, immersion in problem solving, and not perceiving the passage of time during class. This motivation was also evidenced in the self-assessment phrases of students: "What I liked the most was to create the objects with which we produce the sound effects"; and "To make the recordings of the sounds.". There were also comments on the self-assessment, associated with motivation for problem solving: "[I liked] the puzzle"; and "What I liked the most about these activities was messing with the inclined plane to try to have a better sound than the previous one.". When asked what they disliked the most, none answered the hands-on activities or the digital assembly, but the written registers they had to perform, e. g., "written activities less interesting". In the self-assessment, students also complained about the time spent on the project overall, e. g., "[I disliked] the [time] duration that the project took". In fact, without the modern digital tools the developed project would have been even more time consuming, if not unachievable.

Regarding dimension IV, i.e., proactivity and communication between peers (within the group), most students achieved a "good" or "excellent" level. They could perform effective collaborative work sharing ideas and testing each other's solutions, but only the "excellent" level performers could do so in the available time. For example, group 1G and 1E stood out by exploring the simultaneous execution of various sound effects, with different elements of the group operating a simple artifact in synchronization. In this example, each element of the group was essential, thus reinforcing teamwork and cooperative learning, which led to a unique and relevant sound effect. Yet these two groups presented different levels in dimension IV, "excellent" and "good", respectively, since as compared to group 1G, group 1E had difficulty managing time and carrying out effective work. Due to this situation, this group, along with 2B, required extra monitoring from the teacher who suggested to them that they divide into two subgroups to be able to achieve the intended goals in the little time remaining. Group 2B still managed to explore some material variations but without new artifact building (in Figure 6b, from Section 3.2, on the right it was written by the students that the assembly on the left was repeated without the rice in the drum surface). Group 2F also required frequent monitoring, being less immersed in the completion of the tasks given (Table 4, dimension III) and one of the members of the group only working when oriented (Table 4, dimension IV).

Table 4. Examples that led to the attribution of the assessment levels to students' creativity regarding dimension III and IV.

Evidence Dimension	Insufficient	Sufficient	Good	Excellent
III: Immersion in the resolution of the problem; feeling of effortless work.	The students were not committed to solving the problems.	The students showed commitment to solving the problems but perceived the passage of class time. - 1F (frequently); - 2F (in two of the classes).	The students showed commitment to solving the problems, not noticing the passage of class time. - The usual warning (from students) that it was already time to leave class did not occur (all groups except 1F and 2F).	The students showed commitment to solving the problems, not noticing the passage of class time. The students worked on the construction of the artifact outside of school time.
IV: Proactivity and communication of ideas to peers.	Students do not present relevant ideas, or refuse to work, even when oriented in that direction.	Students present some relevant ideas, working only when oriented in that direction or having some trouble presenting ideas to peers. - Students only worked when oriented (2B, 2F).	Students present useful and relevant ideas, working actively although with poor time management. - 1A; - 1B; - 1E; - 1F; - 2G.	Students present useful and relevant ideas, actively working in the time available and encouraging the participation of all for the application of their ideas in useful time. - 1C; - 2A; - 2C; - 1G; - 2E.

In general, students evidenced motivation to do the group work, with a great majority of "good" and "excellent" levels in the "Flow" dimensions III and IV. Still, the students mentioned in the self-assessment that: "[I liked] when I worked in a group with my colleagues in such a more unusual project"; and "I really liked having applied to theoretical classes practical/physical project and doing a cooperative work". In the case of the NASA videos (Videos S1 and S2), the fact that each shift made a video led to the development of the sense of project in a large group context. The same happened in the context of the whole class in the case of the production of the soundtrack for the 25th of April video (Video S3): "I liked to do a project with the whole class".

To reiterate, students were able to embark on the proposed project, assembling, in group, a soundtrack by producing sound effects with the phenomena of physics studied. Most of the students showed commitment during the classes, either in a full class context, in each shift (half-class), and in each group. Furthermore, students cooperatively faced problem solving at three moments. First, while producing the sound effect, second, while digitally recording the sound effect, and third, by matching sound to animation. The first problem was solved by exploring different sound effects (exploring timbre, melody, and rhythms) using different physical artifacts (not digitally based). In the second problem, questions associated with digital recorder saturation, placement, and background noise were addressed or perceived by students. In the third problem, students encountered challenges in synchronizing sound effects with the video's visuals. It is worth noting that it was indicated in the field notes that "Students were impressed by the fact that they could record with a professional microphone subject to calibration and special care". This is one example wherein the complexity associated with the art of sound design for a soundtrack forced students to use new instruments with different sensitivity and care as compared to the instruments used in everyday life, and may have led to the development of transversal skills. Moreover, the constraints of the task at the level of synchronization and of the

phenomena of physics to be used had a positive effect on problem solving and on the development of students' creativity.

Concluding, the groups usually worked as a team in a functional and effective way, communicating and applying their ideas to solve the problems encountered in the iSTEAM tasks. In this way, the students developed their creativity in the construction of the artifacts and in the digital assembly of the sound effects with the video timeline. Therefore, students were able to achieve the iSTEAM task's main goal, to produce a video's soundtrack.

4. Discussion

With this research, we aimed to contribute to increasing the existing knowledge on iSTEAM education regarding students' creativity, since it is scarce and many gaps remain to be explored [7]. More specifically, this study sought to examine the impact of didactic iSTEAM tasks on the development of students' creativity levels while also using digital competences, as stated in the research question.

We argue that the findings of this study could contribute to reinforcing iSTEAM education as a student-centered approach where teamwork, problem-solving skills, and creativity levels can be developed. Furthermore, the essential learning associated with teamwork, communication, and autonomy could be developed by the students as predicted in the literature [4,9,13] for STEAM didactic tasks.

The existing literature is concordant with our findings, wherein it is suggested that STEAM education aims to enhance and develop creativity, maintaining the focus on student-centered learning, where students investigate, communicate, and solve problems [8]. We also agree with Toma and Greca [17] when they say that STEAM education can be a more effective methodology to address problems and find solutions while students maintain a positive attitude and motivation. These authors go further and state that students' positive attitude and motivation can promote interest in scientific subjects, and science in general.

STEAM education and its integrative model, iSTEAM, allow for the interconnection between the various disciplines involved, mitigating boundaries, and taking advantage of the nature of each one, as referred to by Ortiz-Revilla et al. [21] and Thibaut et al. [4]. With the didactic intervention of this work, students were able to take advantage, for example, of the technology accessible through their own smartphone to perform measurements of the sound intensity of the sound effects produced, or take advantage of mathematics to analyze these measurements. In the planning, assembly, and regulation of the artifacts produced, students were also able to experience basis of engineering described by Stretch and Roehrig [34], for example, in the calibration of the sound level meter and of the professional sound recorder. On the other hand, science, in addition to being indirectly associated with what has already been written, was also used in service of the intended purpose. That is, by knowing different forms of energy, and by manipulating them through the built artifacts, the students were able to produce the desired sound effects. Regarding the arts, they were deeply interconnected with all of the other disciplines since the STEM disciplines provided the means to the intended artistic goal: to produce a video soundtrack. This integration of the arts agrees with Yakman's STE@M framework [11], where we went beyond simply adding the arts, going against what often constitutes a lack of conceptualization of STEAM [35]. We agree with Vries [35] when they state that the STE@M framework of Yakman does not address creativity involved in the higher synthesis of knowledge, and we consider that our work can contribute to filling that gap. We also agree with Vries [35] when the author state that by broadening the STEAM education framework with the integration of the empirical domain of scientific creativity, the "A" of arts is no longer just added, from STEM to STEAM, but it creates a unique and essential component that increases scientific creativity and innovative thinking.

As described by Aguilera and Ortiz-Revilla [7], different research articles concerning STEAM are not in agreement regarding to what measure the different disciplines can be integrated, and the differences increase if one questions if and how creativity development can occur and be measured in STEAM didactic interventions. We agree with an iSTEAM

framework where all the five disciplines are interconnected in each task and, indeed, in our work the arts were always present and not just used aesthetically, as previewed by Yakman's STE@M framework [11], since the aim of the students' project was the creation of an artistic product: the soundtrack of a video. Moreover, in agreement with the iSTEAM framework (e.g., [8,20]) we argue that our approach allowed students to perform iSTEAM tasks with a purpose important to them and to have a final product, i.e., to produce a soundtrack for an existing animation video or a sequence of images (turned into video) produced in history class. The themes chosen were appealing for students, such as the space theme, i.e., How to land on Mars, and video images from the Portuguese 25th April revolution. As referred to by Vries [35], the space theme is very appealing for students, disregarding their cultural background. As for Portuguese students, the video about the 25th April revolution is culturally and historically relevant for students, especially due to the current year being the 50th year celebration. The motivation of the students was evident during the observation of the classes, and was also referred to by most students in the self-assessment. In addition to the engaging themes, the resolution of problems within the "umbrella" [21] of STEAM also contributed as a motivating factor. This type of "hands-on" activity also creates a naturally integrating environment for the disciplines involved, since students are able to (and want to) use as many tools as possible in the limited time available. The fact that this type of task is centered on the student, in which the student has an active role in his learning process, might also have contributed significantly to the motivation of the students [21].

This study can also contribute to the importance of including the "A" of the arts as compared to STEM education. As mentioned by several authors, STEAM education can allow for the development, in students, of various skills naturally incorporated and developed in the arts, such as creativity [9,13]. We can argue that during the development of iSTEAM tasks students were able to develop their creativity levels and apply them to solving problems at different levels. We agree with Connor, Karmokar, and Whittington when they say that creativity, as well as other skills, can be developed by any individual [28], since we observed different levels of creativity in students and the majority of students could apply their creativity at good and excellent levels. Some authors, such as Zabelina [36], define creativity as "the ability to produce work that is both novel and meaningful or useful as opposed to products that are trivial or bizarre". Runco and Jaeger [37] go further and argue that it is the process leading to product development that is creative, reinforcing the STEAM education potential to develop creativity in students. On the other hand, Lou, Chou, Shih, and Chung [38] consider creativity in STEM as intuitive, authentic, and naturally occurring, but we agree with Stretch and Roehrig [34] that this is a disputed claim, since creativity is a skill with the ability to be developed and used by all individuals, and therefore all students have creative potential [28,34].

We can also suggest that the "Nature of Arts" and, extrapolating, the "Nature of STEAM", may have contributed to the development of creativity competence in students, in agreement with Boy [9]. That is, as mentioned by Connor, Karmokar, and Whittington [28], a specific type of learning in the arts, "Studio based learning", can be used, in which the resolution of a more complex problem (or learning) is found from its simplest elements. This was achieved with the initial exploration of simpler sound effects, to which complexity was added using layers, leading to the resolution of more complex problems in the final iSTEAM tasks for the construction and production of sound effects.

Specifically regarding music, as the art involved in STEAM tasks, research works are rare. One example is the work developed by Cheng et al. [39] while building musical instruments in a primary 4th grade class using STEAM didactic tasks. These authors also found an increase in students' creativity as a result of STEAM methodology. Another work, by Gregorio et al. [40], with students at a similar age to the students of this study, also describes a STEAM methodology approach that could promote creative problem-solving skills in students. These authors argue that not only can the arts help to connect the different

disciplines of STEAM but, from the other perspective, these can also help to bring the STEM disciplines into an art class (music technology in this case).

It is important to mention that the produced sound effects, by the students, needed to fit the soundtrack of a video. As such, each sound effect had to have a specific position on the video timeline and be consistent with the image. This led students into complex problem solving, where the sounds produced had to be explored at the level of sound height (frequency), timbre (sound wave shape), and synchronization (time). The complexity associated with the iSTEAM tasks developed with the students in this work was important for the students to develop their creativity as applied to problem solving, as predicted by Boy [9]. This complexity also led students to develop diverse skills and attitudes transversal to the experimental and exact sciences. The complex problems students need to solve to perform the sound–image assembly and synchronization were in part resolved during artifact construction, but also when using digital assembly tools and digital effects. That is, alongside the soundtrack production and image-video assembly and synchronization, students were required to use and develop their digital competences. Therefore, digital competences were essential for students to achieve the final goals of these iSTEAM tasks.

It can also be said that it was possible to cross the boundaries between the different disciplines to the detriment of their individual application, such as is intended in iSTEAM tasks [20,21]. Different learning strategies, such as content integration, problem-based learning, project-based learning, and cooperative learning, were also applied under the "umbrella" of the integrative STEAM education model [4]. It should be noted, however, that as described by Zeidler [13] and Ortiz-Revilla et al. [21], there were some problems in the implementation of STEAM education tasks in a school context. The students were more accustomed to operating in individual "silos" of each discipline and with the institutional separation of the latter. Although not a focus of this work, we observed evidence of the latter in the interpretation of texts or in their historical contextualization, in the interpretation of values obtained in relation to their physical meaning, in the calculations associated with the conversions of units, and in a critical sense in the interpretation of results.

Therefore, we consider it important to develop iSTEAM tasks with students so that they experience and understand what connects the different silos, and that it is that connection that can enrich knowledge and better help to solve problems, as intended by Yakman [11] when the author introduced her STE@M framework.

After this pedagogical intervention we believe that students will be better prepared for future projects in "context-based science education" [1], which focuses on solving complex problems that students will have to face in the future, such as sustainability and climate change. That is, agreeing with Boy [9], we can say that the complexity associated with the nature of the arts, developed in this work, can provide the necessary tools to develop creativity in students. These tools can, in turn, help students to perceive the complexity inherent to problem solving in the modern and real world.

5. Conclusions

In conclusion, it can be stated that the iSTEAM didactic tasks allowed students to develop creativity while using digital competence. Competences associated with creativity and digital competence will be fundamental in the 21st century, and this work could contribute to reinforcing integrated STEAM education as an effective methodology to develop these competences in students.

The main limitations of this study are related to the number of participants and the specificity of the age interval considered. Regarding the first limitation, i.e., the number of participants, we argue that although this poses a constraint for generalizing findings, conducting studies with a large number of participants can impact the effectiveness of the learning process and the proximity of the work that is carried out with students. Additionally, having a higher number of participants often involves the use of more generalized data collection instruments, such as questionnaires, which are less in-depth and personal, as compared to an observing participant with field notes and students'

registers, introducing other limitations to the results. In terms of the second limitation (age interval), we acknowledge that the iSTEAM tasks could be adapted to other ages and other curriculum grades, and that could be a subject of further studies. Additionally, it would be interesting to investigate this type of approach in terms of the teacher's perspective, considering some general misconceptions regarding creativity development in students and in science subjects.

Finally, this study contributed to highlighting STEAM education in relation to STEM education, having allowed the arts to be a factor introducing complexity into the problems that students had to solve. This complexity has led students to develop not only their knowledge associated with the domain of energy, but also their creativity and digital skills, as well as transversal skills to the experimental and exact sciences.

Supplementary Materials: Video S1: with soundtrack performed by students from groups 1A, 1B, and 1C—"Turno 1", YouTube unlisted link https://youtu.be/-Ktt9zzk08g (accessed on 15 April 2024); Video S2 with soundtrack performed by students from groups 2A, 2B, and 2C—"Turno 2", YouTube unlisted link: https://youtu.be/4_bpIeSpJZM (accessed on 15 April 2024);; Video S3 with soundtrack performed by students from groups 1E, 1F, 1G, 2E, 2F, and 2G—"Turma 25 de Abril", YouTube unlisted link: https://youtu.be/AGSey88Uv9c (accessed on 15 April 2024).

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Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to ethical reasons.

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

Appendix A

Table A1. Topics and subjects explored in each area of STEAM education's disciplines in the didactic tasks developed with students.

	S	T	E	A	M
Initial exploratory tasks: How to Use Physical Phenomena to Produce a Soundtrack: Free Fall, Inclined Plane and Fall and Bounce.	Different forms of energy. Units. Measurement. Gravitational potential energy. Kinetic energy. Energy dissipation. Mechanical energy. Law of mechanical energy conservation.	Smartphone/tablet application. Phyphox. Online unit converter. Phet simulator of energy.	Understanding of the operation of a detector and its calibration. Elaboration of a scheme. Simple artifact construction, exploring the different materials available.	Historical contextualization. Sound experimentation through the sound energy dissipated when impacting the ground (with exploration of timbre, height, and intensity). Historical artifacts. Sound experimentation using the simple artifact (with exploration of timbre, height and intensity and time control).	Calculation of gravitational potential energy, kinetic energy, and speed. Interpretation and graphical representation of the measurements. Conversion of units.

Table A1. *Cont.*

	S	T	E	A	M
Final construction task: How to Use Physical Phenomena to Produce a Soundtrack: Construction of the Final Artifact.	Different forms of energy. Units. Measurement. Gravitational potential energy. Kinetic energy. Energy dissipation.	Smartphone/tablet application. Phyphox and Soundcorset.	Planning. Complex artifact construction. Trials and adjustments.	Essays using the complex artifact (with sound exploration of timbre, height, intensity, and synchrony).	Interpretation and graphical representation of the measurements. Conversion of units.
Digital recording and assembly task: How to Use Physical Phenomena to Produce a Soundtrack: Final Recording and Assembly.	Different forms of energy. Units. Measurement. Gravitational potential energy. Kinetic energy. Energy dissipation.	Smartphone/tablet application Phyphox. Digital audio recorder. Audio file listening and selection and organization. Video editing program (remote activity).	Manipulation of the artifact. Calibration of the recorder.	Production of a sound effect with melodies and/or rhythm. Sound effect listening and selection. Synchronization of a sound effect with the images in the video. Exploration of digital effects into sound effects.	Calculation of gravitational potential energy, kinetic energy. Conversion of units. Interpretation and graphical representation of the measurements. Organization of elements in timeline.

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