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How transdisciplinary integration, creativity and student motivation interact in three STEAM projects for gifted education?

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Abstract: The study analyses the relationship between transdisciplinary integration, creativity and student motivation in 3 STEAM projects. It has been carried out over three years in a programme for gifted students. 152 students (11-12 years old), five teachers and four external professionals participated. The projects included a variety of scientific, humanistic and artistic activities, together with outings, the collaboration of experts and the creation of a transdisciplinary art-based final products. The research was carried out through the analysis of qualitative data (interviews, video-recordings, participant observation) using Atlas.ti8 within the framework of Activity Theory and statistical analysis of questionnaires. It shows how the transdisciplinary integration favoured a complex approach to knowledge with an essential role of the artistic-based transdisciplinary final products and fostered a plural approach to creativity.

The active participation of the students favoured their motivation and involvement. The significant correlation between creativity, student motivation and transdisciplinary integration emerges as a key element in the STEAM projects implemented.

Keywords: STEAM; gifted education; primary education; creativity; transdisciplinary integration; student motivation.

The integration of scientific areas (Science, Technology, Engineering and Mathematics) and the arts (STEAM Education), has aroused a growing interest in literature, becoming one of the key educational trends from the last decade. However, it has been highlighted certain vagueness in its pedagogical concreteness and research (Colucci-Gray et al., 2017). There is a wide consensus in literature (e.g., Perignat & Katz-Buonincontro, 2019) identifying three consubstantial elements in STEAM Education: curriculum integration, creativity, and student motivation. From this perspective, three transdisciplinary STEAM Projects for 11-12 years old students were designed and implemented during three years in a Program for Gifted Students in Comunidad de Madrid (Spain). We aimed to analyse the defining learning characteristics of the implemented projects, as well as the interaction between the three fundamental axes: curriculum integration, creativity and motivation.

STEAM and gifted education: disciplinary integration, creativity, and student motivation

Curriculum integration is implemented from various methodological perspectives in STEAM education, such as inter- or transdisciplinary (e.g., Liao, 2016). A transdisciplinary approach adapted to gifted education is described by Lage-Gómez and Ros (2021), based on the concept of Big Idea as a thematic axis from which blurring the boundaries between the areas (Chalmers et al., 2017). In this line, the interrelations between the diverse areas might be addressed after elaborating on its specific content (Kelley & Knowles, 2016). So that, the transdisciplinary integration might open new ways of knowing in a process of reconfiguration of the educational space, experiencing real world complex problems (Burnard et al., 2022). For example, Akhan et al. (2022), explored the global problem of climate change with gifted students from an integrated perspective, underlying how students produced critical and creative solutions. As suggested by Little et al. (2007), curriculum integration practices in gifted education increase the conceptual reasoning, critical thinking, and content learning, establishing a framework which favours the student engagement in actively exploring, analysing, and discussing advanced materials and topics. So that, Tucker et al., (1997) considers an integrated-thematic curriculum as appropriate for gifted learners considering their high abilities to establish relationships.

Creativity in STEAM education might be approached from a plural perspective where a series of psychological, behavioural, social, and cultural aspects operate simultaneously (Glaveanu & Beghetto, 2021). Several authors (Burnard & Colucci-Gray, 2020; Costantino, 2018; Quigley et al., 2017) suggest the relationship between creative thinking, creative skills, innovation, and imagination connected to STEAM. This perspective might be applied to gifted education, even more when considering the creativity as one of the defining traits of giftedness, along with high intellectual ability and perseverance to the task (Renzulli, 1999). From the perspective of the interrelationship between teaching for creativity, teaching creatively, and creative learning (Jeffrey & Craft, 2004), and considering creativity not an inherent psychological trait (DeHaan, 2009), STEAM education for the gifted might foster a plural approach to creativity from the diverse areas.

Starting from the conception of intrinsic motivation as a predictor of creative skills and domain knowledge (Amabile, 1996), Conradty & Bogner (2019) quantify creativity in STEAM projects with adolescents, indicating that younger students' creativity scores are higher than those of older ones, and underlining the importance of creativity as an essential starting point for student motivation, correlating creativity and motivation. In this sense, Bybee (2006) underline the relevance of manipulative and inquiry activities typical in STEAM to enhance student motivation and learning. Dieker et al. (2012) reported the benefits of STEM projects in gifted education in fostering student self-confidence. This is correspondent with the open perspective on cooperative work and its positive effects on collaborating with friends (Shore, 2021). Cho and Lin (2010) correlate intrinsic motivation with the participation in specific programmes for creative problem-solving approach to maths, "the longer they participate in the gifted education program for creative problem solving approach to maths, the higher their intrinsic motivation becomes" (p.55). In addition, it is important to consider the critical function of family, by enhancing indirectly intrinsic motivation and confidence in intelligence. As suggested by Heller (2007), social learning environments plays an important role in gifted education, emphasising creative environment and experimental possibilities.

There are several propositions in the field of gifted education that allow to address the mentioned three consubstantial aspects of STEAM in school projects. Sternberg (2020) proposes the Augmented Theory of Successful Intelligence. The author underlines the following characteristics:

(1) Carrying out varied kind of activities.

(2) Helping students to capitalise on their strengths and compensate for their weaknesses.

(3) Promoting a flexible environment with opportunities to risks taking and think differently.

(4) Activities being balanced between those that are more analytical, practical or more

creative, developing multiple reasoning skills and actions.

(5) Using their knowledge for the common good.

(6) Instilling positive ethical values.

In a similar vein, Wilson (2018) proposes successful characteristics in STEAM activities for gifted education:

(1) Diverse activities, in order to discover individual preferences.

(2) Providing time and flexibility for students to explore and develop their interest.

(3) Contextualize the content with expert professionals' practices.

(4) STEAM activities have the potential to develop deep thinking, as well as develop creativity and visual–spatial skills that are necessary in the STEM disciplines.

As stated by Shore (2021), research evidence in gifted education from specific practices is needed. In that line, the following research questions are proposed from the framework of STEAM education for gifted students:

(1) What are the key characteristics of the transdisciplinary STEAM projects implemented?

(2) How creativity, transdisciplinary integration and motivation are related to the learning processes in the STEAM projects from the student perspective?

Method

The study involves a mixed and multi-method research (Levy, 2017) from the epistemological principle of teachers as practitioner researchers. The research involved students, teachers, researchers, families and external professionals. From a Habermasian perspective, Biesta (2020) proposes a pragmatic approach that integrates the three distinctive purposes of research: explanation, understanding and emancipation. Accordingly, the study aims to balance a deep comprehension of the human action together with its intelligibility through theoretical construction. All this developed from a transformative framework perspective.

Context and Participants

The participants in the study belong to a specific and public programme for gifted students. They are admitted after a psycho-pedagogical evaluation based on standardised tests of intelligence and creativity by the guidance services of their educational centres and after verifying that they meet the Programme criteria. 16 sessions per year, 3 hours each, take place voluntarily 2 Saturdays per month. The programme is organised into scientific-technological, humanistic-literary, artistic and social skills areas.

The participants in the study are presented in Table 1. It involved 152 students in 12 groups of 11- and 12-years old (4 groups in each one of the 3 projects with 8-17 members each), 100% Spanish nationality and mixed by gender. It was run over 3 years, implementing a different STEAM project each year, although they all had the same organisational structure and objectives. The students participating in the projects were different each year. The projects were entitled "Fractals" (2017/18), "Graphs" (2018/19) and "Alice" (2019/20), respectively. The projects were elaborated by a group of 5 teachers-researchers within the context of the gifted programme: one from Primary Education, two from Secondary Education and two from the university, with expertise in the areas of History, Biology, Music Education and Science and STEM Education, respectively. In addition, three external professionals, experts in the topics involved, and two audio-visual production professionals who have edited a video summary of each project, have also participated. It also involved the collaboration of the coordinator of the educational programme and the students' families.

Table 1. Participants in the study.

Participants	**Description**	**Role**
Students	152 students (92 male / 60 female). 11-12 years old. 12 class groups.	Class assistant. Evaluation of the projects.
Teachers Researchers	5 teachers, two of them are also researchers.	Designers of the projects and the research.
Programme Coordinator	1	Supervisor of the programme.
Families	2. Volunteers.	External evaluation.
External experts	3	Collaboration in the activities. External evaluation.

Transdisciplinary STEAM projects

The three projects started from a Big Idea (the mathematical concepts of Fractals, Graphs and Lewis Carroll's Alice books) and had a common structure. First, an introductory session was carried out to introduce the topic and present an initial perspective from each area. The following sessions consisted on specific activities to address the humanistic-literary, scientific-technological, artistic, and social skills fields, and the last one implemented transversally. The programme includes a workshop developed by an external professional and an outing both related to the theme of the project. Finally, a final performance is elaborated collaboratively trying to integrate transdisciplinary the different areas. A summary of the contents implemented in the projects is given next (more details and the link to a video-summary could be seen in the Appendix 1).

Fractals project

The scientific-technological activities consisted of a presentation of the mathematical concept and properties of fractals, different types (geometric, algebraic), and several challenges that involves problem solving abilities. The artistic activities involved the creation of various representations in 2D and 3D working collaboratively, through origami or collage techniques. In addition, musical parameters were fractalized through cooperative composition. In the humanistic area, students created fractal stories in groups based on the concept of self-similarity, which they share with their partners. We visited the Natural Science Museum, and we had a conference about chaos in biological systems. The final transdisciplinary artistic performance integrates the narration of the fractal stories created before, with the interpretation of fractal music, the creation of fractals through technological applications and the collaborative creation of a mural. A video summary is available at link anonymized.

Graphs project

The scientific-technological area started with an historical introduction to the origin of graph theory. Next, students create molecules from the chemical formulation of the elements and their three-dimensional structure, building molecular models. In the humanistic-literary area, the students created a graph collaboratively, connecting common aspects of their personality. In addition, they connected stories and their characters with graphs as well as civilizations with board games based on their common characteristics. The artistic creation was haikus whose keywords constitute the nodes of the common graph whose representations was also translated into music. We visited the Museum of Mathematics. The external professional activity was about embroidery. The students learn the technique, creating their own embroideries where they reflect ideas and concepts learned throughout the project. The final product consisted of an art installation. Based on the embroideries created in the previous activity, students cooperatively build a giant graph inside the courtyard of a historic building in the city. This activity also emphasizes the relevance of the space and place of action in these installations.

Alice project

The scientific-technological activities started with the concept of chirality with everyday examples, working later with chiral molecules, creating models and connecting with the book *"Alice through the looking glass"* and the work of the painter Salvador Dalí. Optical illusions were addressed from the optical phenomena of reflection and refraction of light, connecting to everyday phenomena (lenses, mirrors, mirages) and with simple experiments. Chess is also a key element in Alice book, so this game is used to discover properties of it by means of the theory of probability. The artistic creation focused on the analysis of examples of integration between music and dance based on musicgrams that are created with the Music Eyes software. Besides, a living painting is created based on representations of Alice by Salvador Dalí. The external professional guided the shared play of "Alice in Wonderland".

Instruments

In accordance with a mixed research approach, quantitative and qualitative instruments were selected for data collection. The questionnaire (Appendix 2) consists of several statements and the student must mark his/her level of agreement in a Likert scale (1 minimum - 5 maximum). Before carrying it out, it was explained to the students that they had to evaluate the project as a whole and that there were no right or wrong answers, but that they simply had to be honest. It is divided into three dimensions accordingly to the categories of transdisciplinary integration, motivation, and creativity, with 3 items each. Items were codified with a letter corresponding to their dimension (I for transdisciplinary integration, M for motivation and C for creativity) and a number. The questionnaire does not seek to measure the improvement of students' knowledge or creativity, but rather to collect their perspective at the end of the project on how it fosters aspects related to the three categories of analysis considered.

The validation of the questionnaire was performed following the process proposed by Escobar Perez & Cuervo Martinez (2008), so 5 experts in quantitative research in the educational field assessed each item according to the criteria of clarity, relevance, and coherence. Accordingly, some questions were rephrased. Given the age of the students, the questions were previously explained to them, specifically those referring to the creativity dimension. The questions were compulsory, so the number of answers in each question is equal to the total number of participants (152). The reliability of the questionnaire was measured using Cronbach's Alpha, obtaining values of .67, .58 and .73 in the dimensions of creativity, transdisciplinary integration, and motivation respectively. Given the small number of items in each dimension, these results can be considered valid (Loewenthal and Lewis, 2018).

The qualitative techniques and instruments were:

- Participant observation carried out by the 5 teachers and researchers and collected in their class diary through the established categories.
- Observation of the lessons video recordings by the researchers through the established categories.
- 10 semi structured group interviews with the students from the different projects.
- 3 semi structured group interviews with the teachers and researchers.
- 1 semi structured interview with the programme coordinator, 1 with a parent, and 1

with a collaborating expert.

Procedure

The data was coded and triangulated according to the framework of Activity Theory (Engeström, 1999) through Atlas.ti software (Friese, 2021) and the statistical analysis performed with R software (R Core Team, 2018). The observational and narrative analysis from the qualitative data obtained from the teachers' and researchers' class diaries and class video recordings, together with the data from the 10 group interviews with student at the end of each project, teachers, as well as the individual interviews with the programme coordinator, families, and participating expert, was analysed in a deductive/inductive procedure following the categories of creativity, motivation and transdisciplinary integration in correspondence with the questionnaire.

Inductive codes were set through the Atlas.ti software from the three established categories (creativity, motivation and transdisciplinary integration). The codes were organised according to the components of the Activity Theory: the subject, being the students who are immersed in a learning process within the educational projects, the object following this theory. The relationship between the subject and the object are mediated by a series of mediating artifacts, in this case centred on STEAM education, together with a series of rules and division of tasks that are established within the framework of a project developed in a community of practice. The subcodes were transdisciplinary integration, big idea, creative action, meaningful experiences, motivation, creative spaces for teaching and learning and diverse roles.

The questionnaire was performed at the end of each project by the students. The quantitative analysis involves descriptive statistics and non-parametric estimators such as the Mann-Whitney U test to check for the existence of significant differences by age and gender, the biserial-rank parameter for its size effect and Spearman's Rho (r) for the correlation analysis.

Results

Following the research questions, the results were coded and triangulated, based on the methodological perspective and supported by the theoretical framework. The results of the three STEAM projects and groups are presented jointly, since no significant differences were found in the responses of the questionnaire comparing the three projects, nor across the students compared by age or gender. In fact, the effect size is small according to the biserial-rank parameter, which is below 0.2 when comparing genders, ages, or projects. In addition, the projects had same organisational structure and were run using the same methodology and pedagogical principles. These allows to reach a global answer to the proposed research questions.

Key Elements in the Transdisciplinary STEAM Projects

A series of characteristics that define the transdisciplinary STEAM projects for gifted education are presented. The boundaries between areas are blurred through the big idea perspective, as a student evidenced "all the activities revolved around Alice" (Student 1, group interview 2, 28 November 2020) and crystallized in the final creation, obtaining a holistic perspective of learning, as it was stated by a student: "we have learned to see a thing from different points of view" (Student 2, group interview 2, 28 November 2020). The key role of the final artistic-based performance in the transdisciplinary integration process is stressed by the programme coordinator because "visualising it so graphically makes it easier to understand in depth the content, at least, in the scientific area, which is quite abstract" (Programme coordinator, interview, 30 October 2019). It is also confirmed from teacher's perspective: "In addition, in those joint sessions, is where they have best integrated that knowledge they have seen from each area, because in those artistic creations they reflected what they had learned in the mathematics or biology sessions, and it was seen in the embroideries they have done." (Teacher 4, group interview, May 11, 2019). It is possible to infer how transdisciplinary integration favoured a complex approach to knowledge by blurring the boundaries between the diverse areas, as highlighted by one student "we have understood that many things are linked, that there is another world behind the mirror" (Student 3, group interview 1, 28 November 2020). In this sense, a student in the Fractals project stated in a group interview: "we have created fractals, different types of fractals: fractal stories, fractal music, fractal trees, fractal triangles and many more things" (Student 4, group interview, 26 May 2018).

The identification of creativity by the students as a cross-cutting element in all the knowledge areas addressed in the projects has been characteristic of the students' learning processes: "we have created illusions, imaginary worlds and many other things" (Student 5, group interview 1, 28 November 2020). The students have identified creativity as a phenomenon that has allowed them to develop their imagination, as one student pointed out, "we did it by developing our imagination" (Student 6, group interview, 28 November 2020). Through diverse creations they have related and connected the different areas: "in each activity we created something important: we created another reality when developed symmetry, we created a different perception of things, we created illusions. All the activities taught us something important about life" (Student 7, group interview, 28 November 2020).

Creativity was also key in the final artistic products (Figure 1). In this sense, one of the professionals stated: "Leaving it to them has generated a potpourri of colours, of super high connections, they have even brought different painted balls that have brought another different touch that is not simply like the hoops, but with a 3D touch, and the result for me has been quite positive" (External professional, interview, May 11, 2019).

An essential characteristic of the projects is the link to the real world through the diverse activities developed. In this line, different and creative spaces for teaching and learning were used, where students performed a variety of roles, integrating a community of practice with all the participants, including teachers, researchers, and external professionals (see Figure 2). A student underlined the "cooperation between students and groups through fractals" (Student 8, group interview, 26 May 2018), as a key element in the creative processes. Thus, and as one student summarised: "using all areas we have created new things, different spaces, we have seen the world from another perspective and we have learned to cooperate, to imagine strange, new, different things" (Student 9, group interview, 28 November 2020.

Figure 1. Creation process of the art installation in the Graphs project.

Data triangulation evidenced the importance of student active participation, since most activities focused on cooperative learning. In this line, a student referred to the learning process as “enjoyable, funny, cooperative, but sometimes complicated because there was little time and many things to do” (Student 10, group interview 2, 28 November 2020). Families supported the project and were aware of their children's interest and motivation. As one parent pointed out in the interview: "You just had to see the students proudly showing their final work and explaining it to their parents"(parent, interview, 29 October 2019).

Students' satisfaction was evident throughout the project, an aspect which in turn favoured the motivation and a high level of involvement. In this line, and as stated by a parent: "the eagerness to discover and participate in novel activities that are attractive to them, to face challenges and solve them, makes students come to class motivated, and they leave the classroom more motivated because understanding the world gives them confidence" (parent, interview, 29 October 2019). In addition, the role of social skills in the teaching and learning processes was emphasised by the teachers, conceiving it as a key element in the project.

The deductive and inductive analysis by using the Activity Theory through Atlas.ti8 software shows and confirms the valuable relation established between transdisciplinary integration, creativity, and student motivation in the connection between a series of factors

Figure 2. Variety of spaces and participants in the activities.

during the STEAM projects and enhances the significance of learning. All within the framework of a community of practice in which students have assumed a variety of roles in a participatory and motivating process of shared responsibilities in a school socio-cultural framework. This has resulted in the achievement of meaningful learning experiences as a form of creative action across diverse perspectives as an outcome of the transdisciplinary integration projects (Figure 3).

Relationship between Creativity, Transdisciplinary Integration and Motivation in the Transdisciplinary STEAM Projects

The results of the questionnaire are shown in Figure 4. The percentage of responses with a rating below 3 is less than 5% and the highest scores (4 or 5) account for more than 80% in all the items. It reveals that students emphasised the creation of novel products (C2) through a variety of roles assumed throughout the projects in the different areas (C1). All this, as underlined by the students, has allowed them to enhance their own capabilities (C3). The results support the choice of a *Big Idea* to address the different subjects (I1), making connections

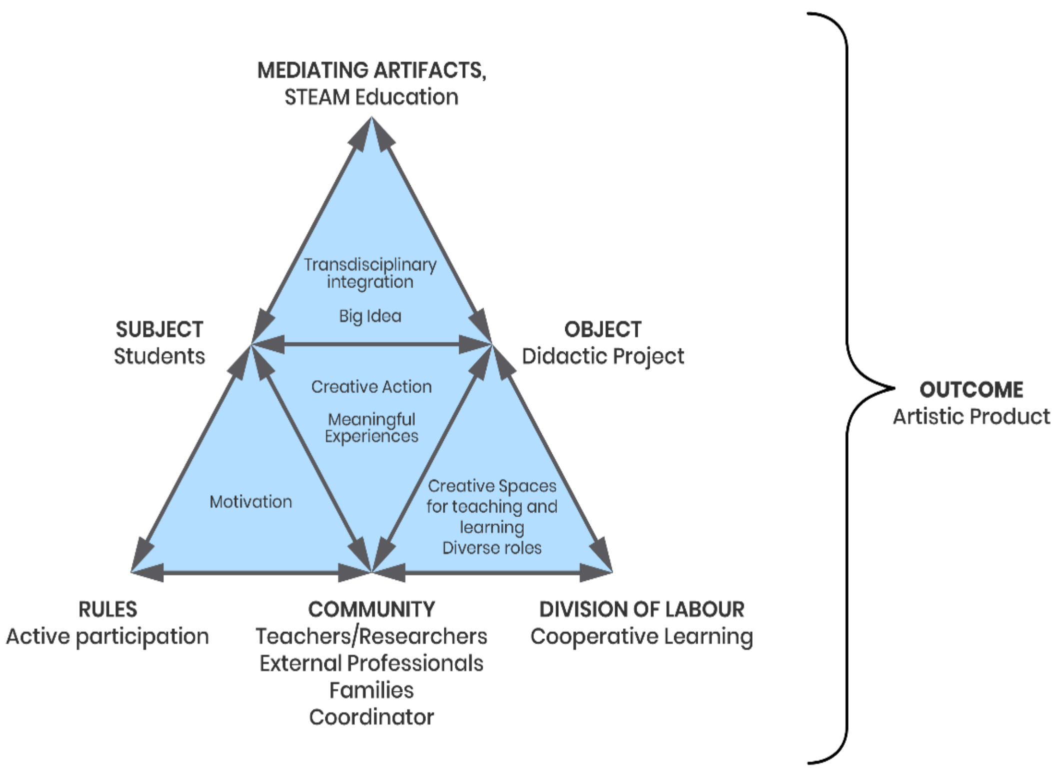

Figure 3. Analysis of the STEAM projects developed through the Activity Theory.

between the diverse disciplines (I2) and successfully integrating them into the creation of the final product (I3), all of which enhance a meaningful learning. The projects were highly motivating for the students (M1), very stimulating for their transdisciplinary development (M2) and, moreover, they feel that their expectations were met in a very satisfactory way (M3).

Correlations between the dimensions of the questionnaire were calculated from the median of the items belonging to each dimension for each student. The values are .40 between creativity and transdisciplinary integration, .54 between creativity and motivation and .53 between transdisciplinary integration and motivation. These correlations are statistically significant ($p < .001$). In the case of our study, this suggests that addressing creativity from diverse disciplines, seeking for connections between areas and integrating knowledge in a final

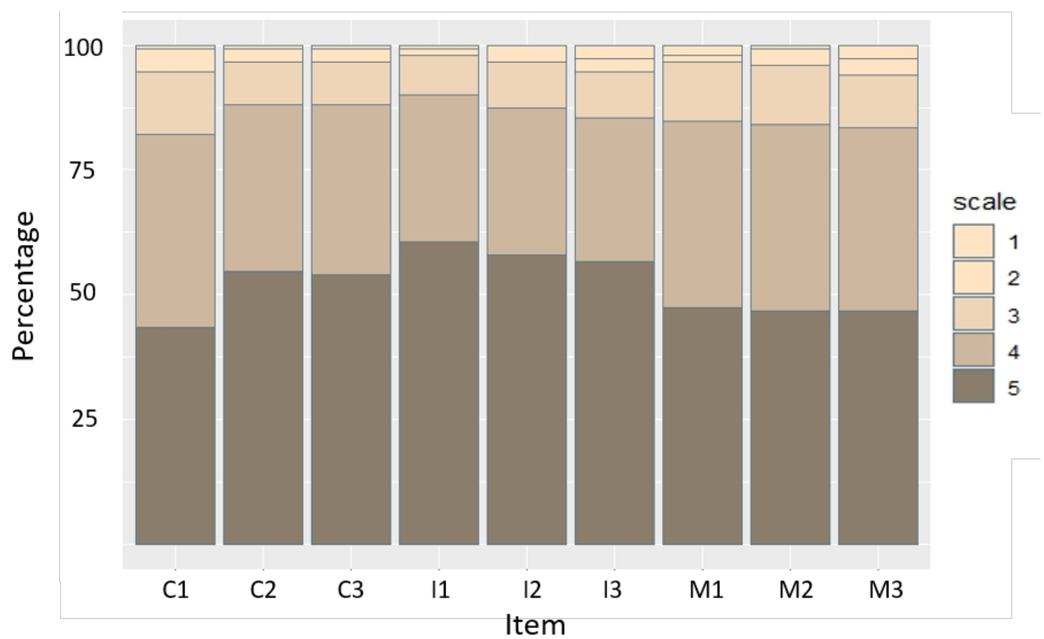

Figure 4. Percentage of responses to the questionnaire (1 minimum - 5 maximum).

transdisciplinary project encourages a complex understanding of the contents addressed, and fosters students' perception of their own creativity in a highly motivating and stimulating learning processes. The lower correlation between creativity and transdisciplinary integration is due to some specific items as discussed below.

The degree of correlation between the different items of the questionnaire is also shown in Appendix 3 for a more detailed overview. A positive and significant correlation has been found between most of them. Some of these correlations are particularly noteworthy. Thus, results suggest that the design of the projects is highly stimulating to the students (M2) due to the achievement of a high level of development of their creative abilities (C3; $r=.53$; $p<.001$) and a better understanding of the content areas (I1; $r=.54$; $p<.001$). The high level of motivation during the activities (M1) also correlates stronger with their perception of a deeper understanding of the contents (I1; $r=.50$; $p<.001$) and with the other motivational items, as finding the project stimulating (M2; $r=.59$; $p<.001$) and having met their expectations (M3; $r=.51$; $p<.001$). On the other hand, the lower and not significant correlations suggest that adopting different roles (C1) or creating new things from each area (C2) does not provide the students' feeling of having related the different areas (I2; $r=.10$ with C1; $r=.19$ with C2). It also seems that the students have differentiated between what they have created in the various activities throughout the entire project (C2) and the representation at the end of the project (I3; $r=.20$).

Discussion and Conclusions

This study has deepened the analysis of transdisciplinary STEAM projects, addressing the recommendations put forward by Sternberg (2020) in the Augmented Theory of Successful Intelligence. Thus, a variety of activities were carried out from very different areas connecting to real-world problems, starting from a central Big Idea (Chalmers et al, 2017), seeking for connections between disciplines, creating a transdisciplinary final product and promoting flexible learning environments by using numerous spaces and the collaboration with external professionals.

The significant correlation between creativity, motivation, and transdisciplinary integration is evidenced, indicating that meaningful learning experiences are encouraged by running highly motivating projects with a high level of transdisciplinary integration and fostering students' perspective of self-creativity. These results highlight the value of the transdisciplinary STEAM methodology implemented, where a balance between activities focused on the development of practical, analytical or more creative skills with various forms of reasoning were developed. This perspective allowed students to discover their own preferences (Root-Bernstein, 2015). This approach also corresponds to the relationship established by Guyotte et al., (2014) between the developments of creativity, inter-transdisciplinary and cooperative learning in higher education.

In tune with Wilson (2018), we have corroborated the effectiveness of the implemented STEAM projects in our study from the participants' perspective, focused on creative and meaningful learning by gifted students. Furthermore, its relevance for creative learning was confirmed (Henriksen, 2014), as well as the effectiveness of transdisciplinary integration applied to STEAM, as suggested by Salden et al. (2006), and also including Humanities (Quigley et al., 2017; De la Garza & Travis, 2018). The link between motivation and creativity in STEAM established by Conradty & Bogner (2019) has been also supported in this study, together with the significance of social learning spaces (Heller, 2007).

The implementation of transdisciplinary STEAM projects evidences the positive interaction between the methodology developed and the three elements consubstantial to

STEAM education, i.e., curricular integration, creativity, and motivation. The key elements of this methodology are (1) the transdisciplinary approach, (2) the connection between areas from a thematic axis or big idea, (3) the promotion of reflective and creative learning environments in a community of practice that encourage the understanding of creativity from a plural perspective, (4) the involvement of students resulting in a high level of satisfaction.

The results of this study were obtained from three specific projects implemented in a programme for gifted students. Therefore, it is not possible to generalize them in any context. Nevertheless, we consider the methodology presented in the design of the projects might be useful as a model for STEAM projects in a variety of contexts.

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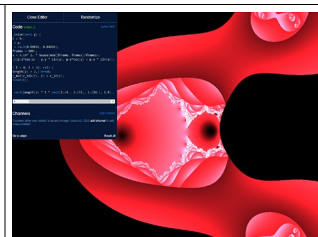
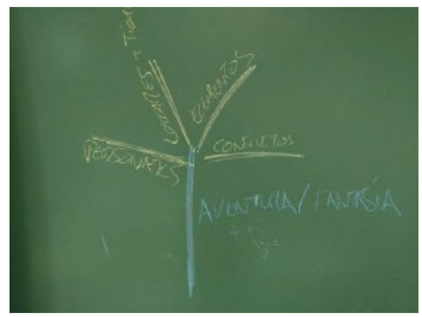
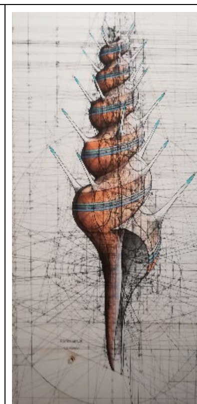
Appendix 1. Summary of the activities of the three STEAM projects.

<table>
<tr><td colspan="2">FRACTALS PROJECT</td></tr>
<tr><td colspan="2">Video summary: https://mediateca.educa.madrid.org/video/jysb7ilq6ru5o2p7</td></tr>
<tr><td colspan="2">Mathematical activities</td></tr>
<tr><td colspan="2">Fractals everywhere (180 min.)</td></tr>
<tr><td>Development:

After the presentation and origin of the abstract concept of fractal, different types are presented (geometric, algebraic), and various challenges are proposed whose resolution involves solving problems, connecting different ideas (fractals and the Fibonacci series) and the search for patterns. They are related to real-world examples (the coast, neural networks, snowflakes, etc.), and their application in fields such as art through music (Bach), painting (Escher) and architecture (Gaudí). Fractals are created with various tools: geogebra, wolphamalpha, etc.).</td><td> </td></tr>
<tr><td colspan="2">Artistic activities</td></tr>
<tr><td colspan="2">Do you dare to create your own fractals? (90 min.)</td></tr>
<tr><td>Development:

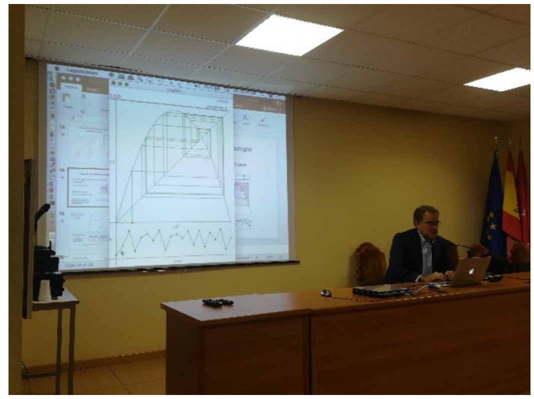
Through techniques such as origami or collage, students create various representations in 2D (Sierpinski tree, Pythagorean tree) and 3D (Sierpinski tetrahedron) working collaboratively.</td><td> 

https://anvaka.github.io/pplay</td></tr>
<tr><td colspan="2">Fractalizing music (90 min.)</td></tr>
</table>

Development: Through collective improvisation, musical compositions are created by fractalizing different musical parameters (rhythm, pitch, intensity).	
Humanistic activities	
Fractal stories (90 min.)	
Development: Based on the concept of self-similarity (basic property of fractals), students in groups create a story with this structure, which they then share as a large group.	
Outing	
Natural Science Museum (150 min)	
Development: Visit to the permanent exhibition and the temporary exhibition of Carlos Araujo, master of geometric drawing and the representation of Nature. Students walk freely through the museum and relate the contents worked on in the project with various elements of the museum (sponges, shells, fossils, trilobites, etc.) and collect their answers and reflections in the worksheets.	 
External professional	
Chaos in biological systems (150 min)	

Development:

A professor from the Faculty of Biology at the *Blinded for peer review* presents the relationship between fractals and chaos, and how it is present in various biological processes, from the functioning of the brain to the beating of the heart. In addition, we relate chaos to everyday phenomena such as the weather and to simple experiments such as the chaotic pendulum.



Final performance

Artistic performance (2 sessions of 180 minutes)

Development:

In a process of integration of all the knowledge and skills acquired throughout the project, students create, develop, and perform an artistic performance. It combines the narration of the fractal stories created before, with the interpretation of fractal music, the creation of fractals through a technological application and the creation of a mural. All this in the large space of the auditorium, achieving an immersive and collaborative nature among students who go through all the roles and tasks throughout the performance.

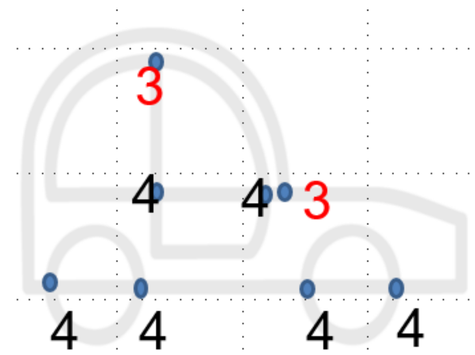
GRAPHS PROJECT

Video summary: https://mediateca.educa.madrid.org/video/ibm73smq1cpim63w/fs

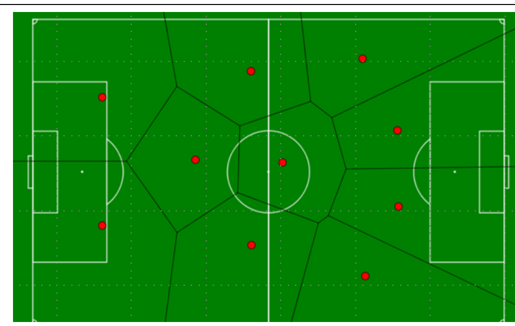
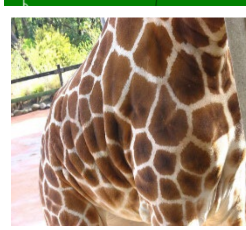
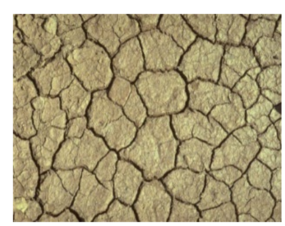
Introduction (180 min.)

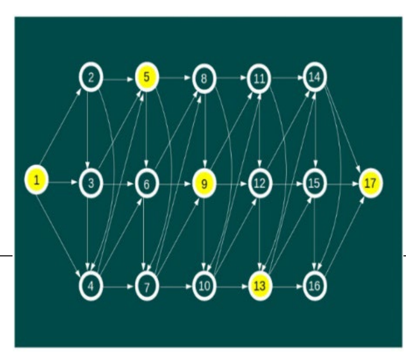
Development:

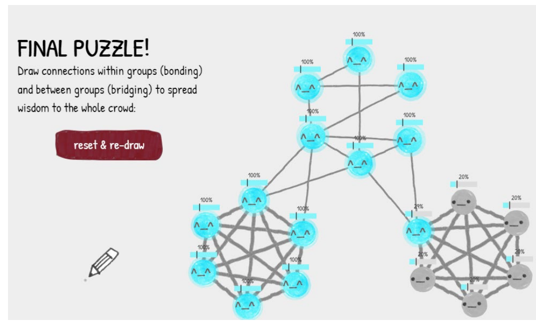
We begin with the historical origin of graphs through the figure of Leonard Euler and the Konigsberg bridge problem. The students solve problems of different Hamiltonian paths analysing if it can be done in a single stroke and when not and

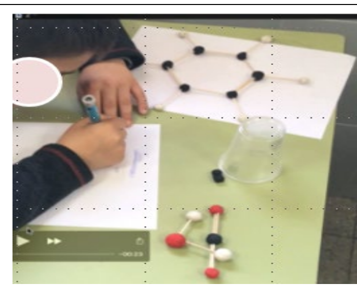
<table>
<tr>
<td>why. Through the story of a fight in a bar and the construction of the associated graph, students discover that in reality the characters are countries, and the story corresponds to the First World War. Finally, a giant graph is constructed in the courtyard in which the nodes are the students from the reconstruction of poems and riddles.</td>
<td>

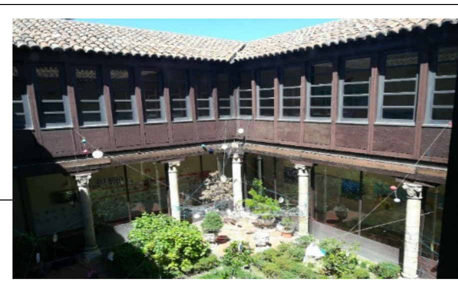
https://www.experiencingmaths.org/</td>
</tr>
<tr>
<td colspan="2">Mathematical activities</td>
</tr>
<tr>
<td colspan="2">Graphs in the real world (90 min.)</td>
</tr>
<tr>
<td>Development:

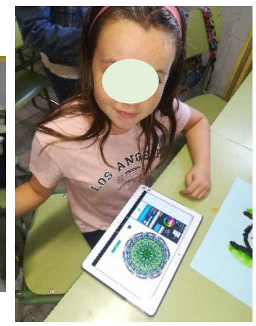
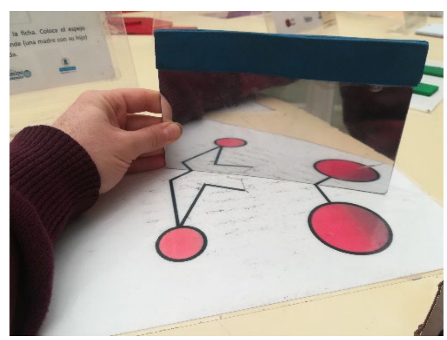
We observed that in nature there are very similar patterns in different situations: the dry earth, the spots of a giraffe, the distribution of cells, etc. After learning the concept of the mediatrix and through several situations with ruler and pencil, we discovered that behind these patterns are the Voronoi Diagrams. Through the mathematical software Geogreba, we applied this concept to examples such as where to place a post office in a city or how to distribute the players on a soccer field.</td>
<td>

</td>
</tr>
<tr>
<td colspan="2">Graphs in logic games (90 min.)</td>
</tr>
<tr>
<td>Development:

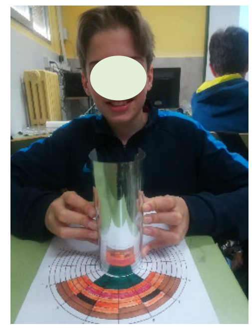
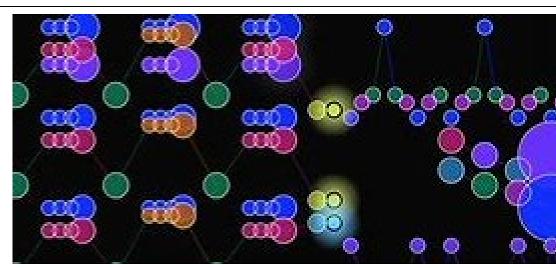
Through various games and challenges, students discover how graphs help us to solve them through the graphical representation of the algorithm or the symbolic</td>
<td>
</td>
</tr>
</table>

representation. Using various applications, they discover and play with the 4-color theorem.	https://mati.naukas.com
Social networks (2 sessions of 90 min.)	
Development: After analyzing the small world theory and the 6 degrees of separation theory and their applications (Facebook, Bacon's oracle, the number of Erdos), students create their friendship graph and test the "friendship paradox". Thanks to a web application, we learn about the types of networks (polarized, isolated, friendly) and their application in the propagation of viruses and fake news.	 The Wisdom and/or Madness of Crowds (ncase.me)
Humanistic activities	
Knowledge graph (90 min.)	
Development: Students playfully and cooperatively create a giant graph connecting common aspects of their personality, developing empathy and group cohesion and affection among the group.	
Connecting Civilizations (90 min.)	
Development: Through board games (Lego, Carcassone), students work in teams to connect different civilizations based on their common characteristics.	

Artistic activities	
Graphonetics and Haikus (2 sessions of 90 min.)	
Development: Students create Haikus from key words that will constitute the nodes of the common graph that is elaborated at the end of the session. In the next session, students set these representations to music.	
Scientific activities	
Creating molecules (90 min.)	
Development: From the chemical formulation of the elements and their three-dimensional structure, students build molecular models with plasticine. Their structure is related to their biological importance.	
The carbon cycle game (90 min.)	

Development: Students learn about the carbon cycle in nature by solving small challenges in each of the stages. The work is done in groups in a collaborative way.	
Outing	
Museum of Mathematics (180 min.)	
Development: Mathematical games where the application of logic and manipulation are crucial to their resolution. In addition, students conduct a cryptography workshop where they build an encryption wheel.	
External professional	
Embroidery (180 min.)	
Development: The students learn the embroidery technique, create their own embroideries where they reflect ideas and concepts learned throughout the project. In addition, the activity delves into the more everyday conceptualization of art and tries to avoid the association of this activity with the female gender.	
Final performance	
Art installation (180 min.)	
Development: Based on the embroideries created in the previous activity, students cooperatively build a giant graph inside the courtyard of a historic building in the city. This activity also emphasizes	

the relevance of the space and place of action in these installations.	
ALICE PROJECT	
Video of the final product: https://mediateca.educa.madrid.org/video/ruj8fsed4711ji2a/fs	
Introduction (180 min.)	
Development: The project based on the books Alice's Adventures in Wonderland and Alice Through the Looking Glass by Lewis Carroll is presented in a large group. After reading and watching some fragments of the books, they gather their suggestions in a brainstorming session. To work on the concept of symmetries, they make drawings on paper and by folding them they obtain symmetrical images. In addition, using a web tool they make drawings based on symmetries.	 
Scientific activities	
Molecules look in the mirror (90 min.)	
Development: After introducing the concept of chirality to the students with everyday examples (such as hands), some chiral molecules are presented, their relevance in nature is explained and models of them are built with plasticine.	
Space and time gone mad (90 min.)	

Development: Through models and in a manipulative way, concepts such as the scales of distances and sizes in the Solar System and black holes are worked on. A connection is established between the role of time and space in the work of Alicia and special relativity, and of the latter with the representation of space and time in the work of Dalí.	
Alice and Optical Illusions (90 min.)	
Development: The optical phenomena of reflection and refraction of light are analyzed through various everyday phenomena, videos and simple experiments. The use of mirrors in art is analyzed and students create their own cylindrical anamorphism.	
Mathematical activities	
Alice, chess and probability (90 min.)	
Development: Through various games in pairs, some properties of the game of chess and the theory of probabilities are discovered, at the same time that mathematical and strategic logic and intuition are developed.	
Artistic activities	
Music Eyes (90 min.)	
Development: After analyzing examples of integration between music and dance (e.g. Tchaikovsky), musicograms are created with the Music Eyes software. In this way students relate music to color and form.	

	https://musiceyes.org/
Living pictures (180 min.)	
Development: Through collaborative work, a living painting is created based on representations of Alice by Salvador Dalí. The polysemic character of art is understood through the book Alice and creative strategies for the realization of living paintings are developed.	
External proffesional	
Expert in theatrical creation (180 min.)	
Development: With the guidance of an expert in theatrical representation, each group worked on the development in interpretation of a scene from the play "Alice in Wonderland". Each group developed its own props and rehearsed the adaptation of the text to the stage.	
Final performance	
Theatrical performance "Alice in Wonderland".	
Development: Each group acted out the scene rehearsed and prepared in the previous sessions, maintaining the storyline of the book.	

Appendix 2. Project evaluation questionnaire

In this questionnaire, you are going to evaluate the project "*Title*" that we have carried out in the programme during this year. There are several statements and you must mark your level of agreement with them according to the following scale:

1- I do not agree

2- I little agree

3- I agree

4- I quite agree

5- I totally agree

There are no right or wrong answers, you should simply be honest.

Code	Item	1	2	3	4	5
C1	I acted as a scientist, writer, musician or artist during the activities.					
C2	We have created new things from all areas.					
C3	Working in this way has allowed me to enhance my capabilities.					
I1	Working with different subjects has helped me to understand the topic better and in greater depth.					
I2	I have related what we have seen in the different areas.					
I3	In the final representation, we have integrated all the activities carried out.					
M1	I was motivated during the project.					
M2	I have found stimulating to work in this way.					
M3	The expectations I had at the beginning of the project have been met.					

Note: The code refers to the dimensions of analysis: C for creativity, I for transdisciplinary integration, and M for motivation.

Appendix 3. Correlations

Table 1. Correlation (Spearman's rho) between the dimensions of the questionnaire.

	Transdisciplinary Integration	Creativity	Motivation
Transdisciplinary Integration	---		
Creativity	.40**	---	
Motivation	.53**	.54**	---

Notes: **p < .001.

Table 2. Correlation (Spearman's rho) between the items of the questionnaire.

	C1	C2	C3	I1	I2	I3	M1	M2	M3
C1	-								
C2	.42**	-							
C3	.37**	.46**	-						
I1	.30**	.43**	.38**	-					
I2	.10	.19	.34**	.36**	-				
I3	.21*	.20	.30**	.25*	.24*	-			
M1	.31**	.35**	.49**	.50**	.21*	.31**	-		
M2	.30**	.47**	.53**	.54**	.33**	.34**	.59**	-	
M3	.36**	.33**	.48**	.40**	.32**	.32**	.51**	.47**	-

Notes: *p < .01; **p < .001.