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Exploring pre-service primary teachers' emotions in a geometry project with 3D design

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Abstract
This study explores the emotions that pre-service teachers (PSTs) experience when they interact with geometric knowledge and 3D design in a project focused on the way of Saint James pilgrimage route. The sample was made up of 101 PSTs from the University of Santiago de Compostela, the final point of the pilgrimage path. An emotional questionnaire, together with a participant observation notebook and a rubric, served as data collection instruments. The analytical frameworks included the didactical suitability criteria for mediational and affective facets, and SAMR (substitution, augmentation, modification, and redefinition) model for the effective integration of technology in schools. The results show a greater presence of pleasant emotions, highlighting the emotions of curiosity and cheerfulness. Despite this, less pleasant emotions such as brain-taster or bewilderment were notable. Pleasant emotions shown, as well, higher correlation rates. In conclusion, 3D design seems to indicate great potential for working on emotions with this group of students.

Keywords: emotions, pre-service primary teachers, geometry, 3D design, STEAM, didactical suitability

INTRODUCTION

There is currently growing interest in the affective domain among researchers in the field of the teaching and learning of mathematics. The affective and cognitive domains are closely linked and form an indivisible whole, which plays a crucial role in the learning process (Beltrán-Pellicer & Godino, 2020; DeBellis & Goldin, 2006; Di Martino & Zan, 2011; Gómez-Chacón, 2000; Gómez-Chacón & Marbán, 2019). In this context, the quest for methodologies, which foster good attitudes among students towards mathematics is crucial. According to Gómez-Chacón et al. (2023), in contrast to other sciences, the relationship between inquiry-based approaches and the affective component of mathematics has received very little attention.

At the present time, STEAM (science, technology, engineering, art, and mathematics) approach is becoming increasingly popular and is being incorporated into the education systems of many countries. This approach combines subjects in a cross-cutting, practical, and contextualized way with two or more disciplines being interwoven towards common goals. It seeks to generate innovation and motivation, helping to break down barriers between logic and creativity. It makes education an attractive process for the majority of students, placing emphasis on inquiry and collaboration with technology playing a key role (Diego-Mantecón et al., 2021; Fernández-Blanco et al., 2020; Meza & Duarte, 2020).

Technology is particularly important in the case of mathematics as, in addition to its benefits on a cognitive level, it helps to promote positive attitudes towards the subject by highlighting its practical applications (Bray & Tangney, 2017; Diego-Mantecón et al., 2019; Gómez-Chacón et al., 2016). In the interaction between mathematics, its practical application and its context, a constant growth can be observed in proposals involving

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Contribution to the literature

- This study presents conclusions about how 3D design influences affections towards mathematics of pre-service teachers (PSTs).
- It specifically presents conclusions about 3D design in relation to emotional component of didactical suitability.
- It presents conclusions about 3D design in relation to mediational component of didactical suitability.

the integration of 3D design and printing (Beltrán-Pellicer & Muñoz-Escolano, 2021; Blanco & Fernández-López, 2023; Cheng et al., 2021; Chien & Chu, 2018; Huleihil, 2017; Kwon, 2017; Ng, 2017; Ng et al., 2022; Tejera et al., 2022). This growing trend reflects how the synergy between mathematics and 3D printing can strengthen and materialize concepts in an innovative way.

This paper presents a preliminary analysis, which aims to identify the emotions experienced by pre-service primary education teachers when dealing with geometrical concepts within a STEAM project focusing on the way of Saint James and supported by 3D design technology, augmented reality visualization and 3D printing. The paper is divided into six sections. The first section provides a brief outline of the current situation of the affective domain in PST training and 3D design as a technological resource. The second section presents the theoretical framework of reference, the theory of didactical suitability by Godino et al. (2023). This section presents the component-specific criteria for mediational face supported by SAMR (substitution, augmentation, modification, and redefinition) model (Puentedura, 2012), and the component-specific criteria for affective facet (Godino et al., 2023). The third section describes the methodology employed and how the project was carried out. The fourth and fifth sections present the analysis and discussion of the results obtained in relation to mediational suitability and, above all, the emotions recorded regarding the affective dimension. The paper ends with the presentation of the conclusions drawn and possible future applications of the study.

BACKGROUND

Emotions in Teacher Training

The affective domain encompasses beliefs, attitudes, emotions, and values concerning mathematics (DeBellis & Goldin, 2006; Beltrán-Pellicer & Godino, 2020). DeBellis and Goldin (2006) define these components of the affective domain, as follows. Emotions are quickly changing feelings experienced consciously, pre-consciously or unconsciously during mathematical activity. They range from subtle to profound and are intricately intertwined with the immediate surroundings and contextual elements. Attitudes describe orientations or predispositions toward certain sets of both positive and negative emotional sensations that are moderately stable. Beliefs imply the attribution of some kind of truth or external validity to the system of propositions or other cognitive configurations. They are often highly stable, highly cognitive, and highly structured–with affect interwoven in them, contributing to their stabilization. Values provide the ethical and moral component to the affective domain, considering personal truths or commitments deeply appreciated by individuals that motivate long-term decisions or set short-term priorities.

According to Gómez-Chacón (2000), a reciprocal, cyclical connection arises between these components and performance. Students' experiences when learning mathematics produce different emotions, which have a direct influence on how their beliefs are formed. This, in turn, has an influence on their attitudes, not only towards mathematics but also towards its teaching. Levine (1996) and Warfield et al. (2005) relate mathematical beliefs with the type of methodology employed and, more specifically, with the degree of student autonomy that the teacher is willing to allow. Simpkins et al. (2006) establish a clear relationship between values, beliefs and opinions on mathematics and performance or the choice of career pathway.

Bailey (2014) and Hodgen and Askew (2007) state that, in addition to occasionally presenting shortcomings in terms of mathematical knowledge, many PSTs experience unfavorable emotions towards this subject. Other authors, such as Jong et al. (2015) claim that PSTs' emotions are closely related to the way in which they approach their teaching practice and the relationships they establish with their pupils. It has been demonstrated that PSTs both claim to experience anxiety towards mathematics and are anxious about teaching the subject itself. In addition, the way their feelings towards the subject evolve during their initial teacher training studies may even be negative (Marbán et al., 2020). Blanco et al. (2022b) and Sakiz et al. (2012) also refer to the influence of the emotional support offered by teachers on students' cognitive development. This support determines students' perceptions of their own ability and is, thus, what drives their motivation and academic performance (Marbán et al., 2020).

In research carried out in our geographical context among pre-service primary teachers, Sánchez Mendías et al. (2011) concluded that PSTs are afraid of mathematics as a subject, they are not keen to broaden their mathematical knowledge and, in general, demonstrate negative attitudes towards it. Furthermore, as Gómez and Caballero (2015) point out, PSTs have a low degree of self-confidence when teaching mathematics. Gómez-Chacón and Marbán's (2019) study makes it clear that if PSTs enjoy learning mathematics, there is a positive influence on their desire to teach the subject and their interest in how it is taught is greater. In addition, these authors claim that mathematical anxiety correlates inversely with the enjoyment of its teaching and directly when an attempt is made to predict attitudes towards the teaching of mathematics. From this perspective, this could be a good treatment against mathematical anxiety and its negative consequences (Gómez-Chacón & Marbán, 2019).

Mathematics & 3D Design & Printing

Although little research has been carried out on their application, 3D design and printing are becoming increasingly important resources in the field of mathematics education, particularly in terms of mathematical comprehension, and have great potential for improving STEAM education and promoting interdisciplinary connections (Beltrán-Pellicer & Muñoz-Escolano, 2021; Blanco & Fernández-López, 2023; Blanco et al., 2022a; Cheng et al., 2021; Hsu & Fang, 2019; Ortiz-Laso et al., 2023; Tejera et al., 2022). Some studies have been conducted in this field, highlighting the levels of education and programs in which proposals for the use of this technology have been made and implemented (Beltrán-Pellicer & Muñoz, 2021; Dickson et al., 2021; Huleihil, 2017; Kwon, 2017; Tejera et al., 2022).

In the context of primary education, Dickson et al. (2021) and Huleihil (2017) propose sequences of 3D design activities for primary school students using *Tinkercad*. These activities focus on the study of measurements, spatial visualization skills, volumes, areas, and Boolean values operations. The conclusions of their research show the benefits of using trial and error strategies, which lead to improvements in academic performance. They also include the advantages, in terms of learning and perseverance, derived from interest and the motivation that this tool generates among students.

Kwon (2017) presents a much broader proposal for secondary education students based on the creation of figures using the SketchUp design software. The data collected in this study show extremely good results in terms of motivation, interest, mathematical competences, and real-life skills among the participants. Tejera et al. (2022). They propose the construction of replicas of real buildings with curves for baccalaureate students using GeoGebra. This study highlights 3D design as an extremely useful tool for connecting classroom knowledge with the real world via an interdisciplinary approach. The results of their study demonstrate an increase in student motivation and the use of higher-order cognitive strategies.

Lastly, Beltrán-Pellicer and Muñoz (2021) present a proposal for pre-service secondary teachers involving the design of a cube that requires taking into consideration those factors, which could affect its bias. In this case, *BlockCAD*, which combines 3D design with computational thinking, was used. The authors highlight the way in which the project transcends the possession of broad mathematical, scientific, or technological knowledge, requiring students to adopt an interdisciplinary approach based on skills, which improve academic performance and beliefs about the subjects involved.

As can be seen, the impact of 3D design on the affective domain of mathematical learning has been examined in various research. These studies have focused mainly on primary and secondary educational levels. This article analysis how 3D design influences the affections towards mathematics of future primary school teachers, specifically at the emotional and mediational facets.

MEDIATIONAL & AFFECTIVE DIDACTICAL SUITABILITY

The notion of didactical suitability, its dimensions, criteria, and operational breakdown were introduced by Godino et al. (2007) as a tool making it possible to move from descriptive explanatory to normative didactics with the objective of effective intervention in the classroom. The didactical suitability of a teaching process is defined as the coherent and systematic articulation of the following six dimensions of suitability: epistemic, cognitive, interactional, mediational, affective, and ecological (Godino et al., 2023). Despite the fact that these six facets are interconnected, recent studies have demonstrated the close relationship between mediational and affective suitability in teaching and learning processes, which seek a change of attitude among students towards mathematics (Beltrán-Pellicer & Godino, 2020; Blanco et al, 2022a). Along these lines, the present paper will focus on these two types of suitability (mediational and affective), both of which have a series of components, which are developed and evaluated via a series of empirical indicators. These serve as a guide when designing and assessing teaching activities, which are being planned or have been implemented.

Mediational suitability is taken to be the degree of availability and appropriacy of the material and temporal resources required for the teaching and learning process to be carried out. **Table 1** shows general criterion of the mediational facet as well as those adequate resources that should be available for optimal development of the teaching and learning process. It is divided attending to four components: material resources, study aids, number of students, schedule, classroom conditions, and time (Godino et al., 2023).

Table 1. Suitability criteria for mediational facet & its components (Godino et al., 2023, p. 19)

Component-specific criteria for mediational facet
Material resources (concrete, virtual, & symbolic)
- Distinguishing mathematical objects (regulative, non-ostensive) from their respective concrete, visual or symbolic representations in mathematical and didactic practices. - Articulating use of configurations of objects & processes on alphanumeric representations with those on concrete representations to progressively enhance processes of generalization, calculation, & mathematical proof.
Study aides (textbooks, exercise books, educational videos, etc.)
- Making critical and reflective use of curricular materials (textbooks or activity worksheets in physical or virtual format, etc.) or educational videos, deciding when and how to use them to support the study process.
Number of students, schedule, & classroom conditions
- Optimizing the number of students to provide personalized attention. - Adapting the classroom and the distribution of students to facilitate interactions. - To provide a schedule of class sessions that favors attention and commitment of students.
Time (collective teaching/tutoring & learning time)
- Assigning adequate time (face-to-face and non-face-to-face) for the intended teaching. - Assigning adequate time to the most important contents of subject & to those that are more difficult to understand.

Table 2. Suitability criteria for affective facet & its components (Godino et al., 2023, p. 20)

Component-specific criteria for affective facet
Emotions
- Designing situations for identification & discussion of emotions to avoid rejection, phobia, or fear of mathematics. - Highlighting aesthetic and precision qualities of mathematics
Attitudes
- Promoting that student assumes responsibility for learning, trying to complete tasks with perseverance, both that require personal inquiry as well as reception and retention of knowledge. - Favoring argumentation in situations of equality; argument is valued in itself and not by person who voices it.
Beliefs
- Identifying students' beliefs about mathematics and its teaching that may condition learning and take them into account in the instructional process.
Values-identity
- Promoting self-esteem so that students feel capable of contributing conjectures & solutions to problems posed, relying on mathematical arguments to convince others of validating of their assertions, thus building a positive mathematical identity.
Interests & needs
- Proposing tasks that are of interest to the students and that are within their reach. - Proposing situations that permit assessment of usefulness of mathematics in daily and professional life.

To ensure the appropriacy of the materials (the first and second components of mediational suitability), the levels of technological integration proposed in SAMR model (Puentedura, 2012) have been considered. This model guides teaching and learning processes for the effective integration of technology in schools. It consists of a hierarchical set of four levels, which makes it possible to evaluate the way in which technology is used in the classroom and to discover the types of uses, which have a greater or lesser effect on student learning (García-Utrera et al. 2014; Puentedura, 2012). The substitution level represents the lowest level of use of technology: one tool is substituted for another with there being no methodological change. In the augmentation level, technology replaces another tool and adds functional improvements, which facilitate the tasks, although there is no change in methodology and the effects on learning outcomes may be minimal or null. The modification level implies a methodological change in which the task being carried out is redesigned by the introduction of technology. The redefinition level implies the creation of new learning activities and environments, which, without the use of the available technology, would be unthinkable. According to this model, the first two levels would suppose an improvement regarding the initial task, while the last two constitute a transformation of the initial task.

Beltrán-Pellicer and Godino (2020, p. 15) define affective suitability as "(t)he degree of involvement, interest and motivation of the students, in a process of teaching and learning of mathematics". Affective suitability is related both to factors, which depend on the institution and to those, which depend on the student and their previous academic history. These authors state that when a student encounters a challenging situation or problem, an effective response is triggered, which is interlinked with their cognitive processes.

Table 2 presents general criterion for the affective facet allowing considering if the instructional process achieve the highest possible degree of students' involvement (interest, motivation, and self-esteem) and consider their beliefs about mathematics and its learning. It is divided attending to five components: emotions, attitudes, beliefs, values-identity and interests and needs (Godino et al., 2023).

MATERIALS & METHODS

The main objective of present study is to determine the emotions experienced by pre-service primary education teachers when working with geometry in a STEAM project, which includes the use of 3D design.

The study employs a type of design research methodology known as teaching experiments (Cobb et al., 2017), providing a theory upon which a certain teaching situation can be tested. The main advantage of this methodology is that it is practice-centered, making it possible to understand the acquisition of specific knowledge and contributing to improvement in education, creating new teaching resources to support learning. Taking the indications of Cobb et al. (2017) into consideration, the criteria of reliability, replicability and generalization must be fulfilled (Cobb et al., 2017).

The sample consists of 101 students, 82 women and 19 men in the third year of a primary education degree taking subject entitled 'teaching and learning geometry'.

Design

The interdisciplinary project combines mathematical learning with the introduction of LKT (learning and knowledge technologies) and the celebration of the Jacobean Holy Year of 2022. The participants designed 3D replicas of emblematic figures of the French route of the way of Saint James and the city of Santiago de Compostela. The final objective was for these designs to be visualized physically via 3D printing (Blanco & Fernández-López, 2023). The project consisted of three phases:

(1) creation of 3D designs,

(2) generation of designs in augmented reality, and

(3) situating the designs and markers on a map.

Tools

Three tools were employed for data collection: a notebook, a rubric and an emotion questionnaire. The notebook was employed based on non-systematized participant observation. The assessment rubric aimed to evaluate the designs created according to the following categories: 'scale and proportion'; 'correctly aligned elements'; level of precision and detail'; 'likeness to the real figure'; and 'appropriate choice of the geometric shapes employed'. The emotion questionnaire was adapted to the context from Gómez-Chacón's (2000) mood map and focused on the analysis of emotions taken to be rapid changes in feelings in response to a meaningful event for the individual (Gómez-Chacón, 2000). The tool consists of 14 moods: *curiosity*, *cheerfulness*, *liking*, *calm*, *amusement*, *confidence*, *just great*, *bewilderment*, *brainteaser*, *despair*, *indifference*, *hurry*, *boredom* and *blocked*. The response range encompassed Ø (not experienced) and X (experienced). This tool sought to evaluate students' emotional responses following each of the sessions in relation to the affective experience of the integration of LKT and working with geometric and didactic contents. Choice of this questionnaire was determined by comprehensiveness of its items, as well as its accessibility and ease with which it can be completed.

As far as the data analysis is concerned, two tools were applied for each of the types of suitability. For the study of mediational suitability, the criteria of the mediational facet (Godino et al., 2023) were applied, along with SAMR model (Puentedura, 2012). As regards the analysis of affective suitability, the criteria of the affective facet (Godino et al., 2023) were employed, focusing on the 'emotions' component, which is complemented with Gómez-Chacón's (2000) mood map.

Carrying Out Project

This section provides a detailed description of how the different phases of the project were carried out:

(1) creation and printing of 3D designs,

(2) generation of designs in augmented reality, and

(3) situating designs and markers on the map.

During the phase of creating 3D designs, work was carried out on concepts of three-dimensional geometry related to geometrical shapes, measurements, proportionality, and perspectives of a shape. *Tinkercad*, a free 3D design program was used. This software is based on constructive solid geometry, enabling users to create complex shapes via Boolean operations (union, split, intersection and difference) on elementary geometrical shapes. The aim of the proposal was to generate three-dimensional graphic representations of architectural elements of the French route of the way of Saint James and the City of Santiago de Compostela.

Figure 1 shows two students working with two screens. On one screen, they are looking for

Figure 1. Students searching for different images of an architectural element to design it in *Tinkercad* (Source: Authors' own elaboration)

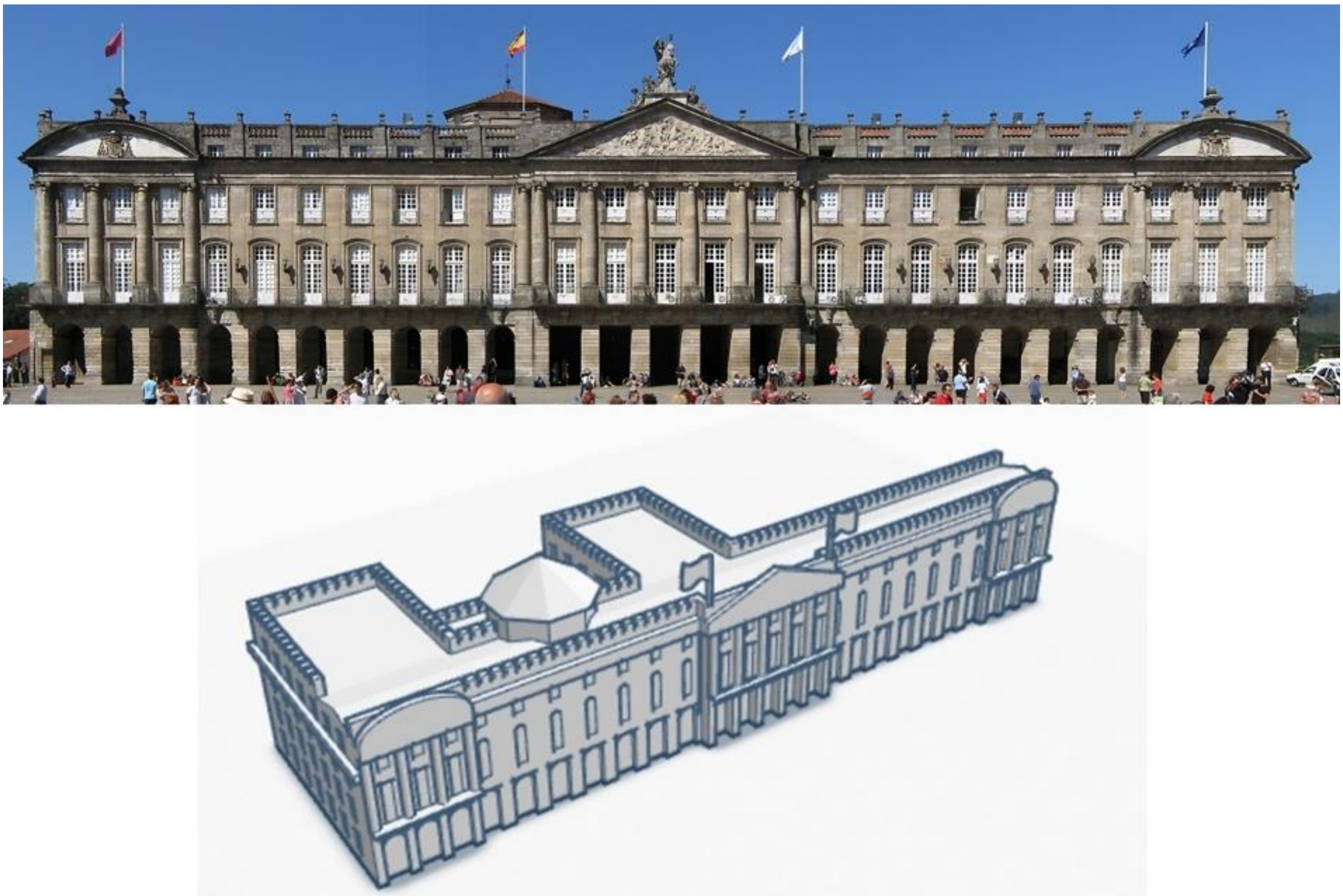

Figure 2. Reference model & design of City Hall of Santiago de Compostela (Source: Authors' own elaboration)

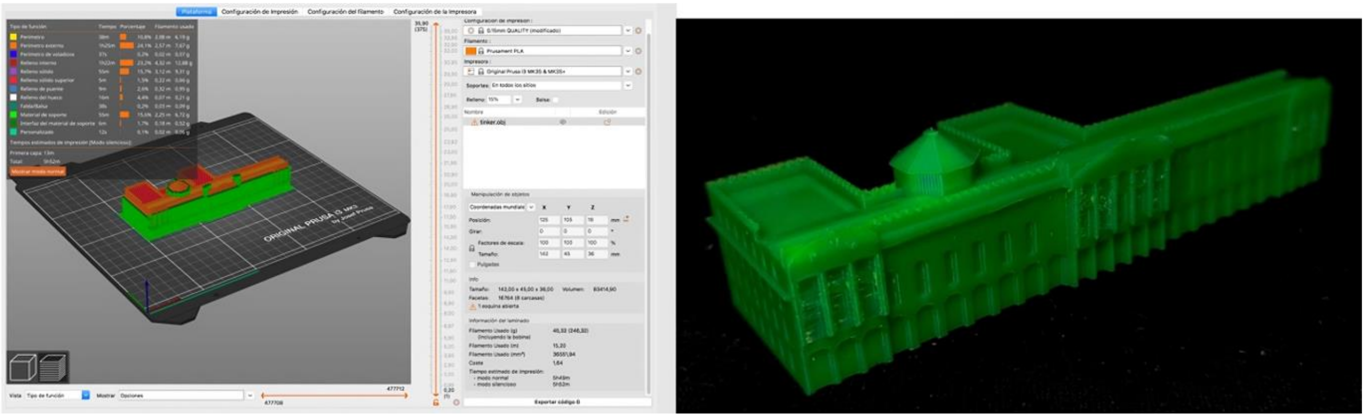

Figure 3. City Hall of Santiago de Compostela in *PrusaSlicer* & its 3D print (Source: Authors' own elaboration)

representations of the architectural element they have been assigned, while on the other, they are working with *Tinkercad*. The project sought to have an effect on visual identification, perceptual consistency, the perception of spatial positions and relationships, visual discrimination and mental rotation.

Figure 2 shows the reference model and the design created for the *specific case of the City Hall of Santiago de Compostela.*

The designs created in *Tinkercad* were laminated using the *PrusaSlicer* application, which makes it possible to modify the printing parameters and transform the final result into G-code to be printed in 3D.

Figure 3 illustrates the laminating process and the result of the printing for the City Hall of Santiago de Compostela.

Phase II originated as an alternative to the physical printing of all of the figures due to reasons of sustainability, time and expense. In this phase, designs in augmented reality of all figures created in the previous phase with *Tinkercad* were generated. To carry out this step, the *Creator* software tool was used in combination with the augmented reality educational

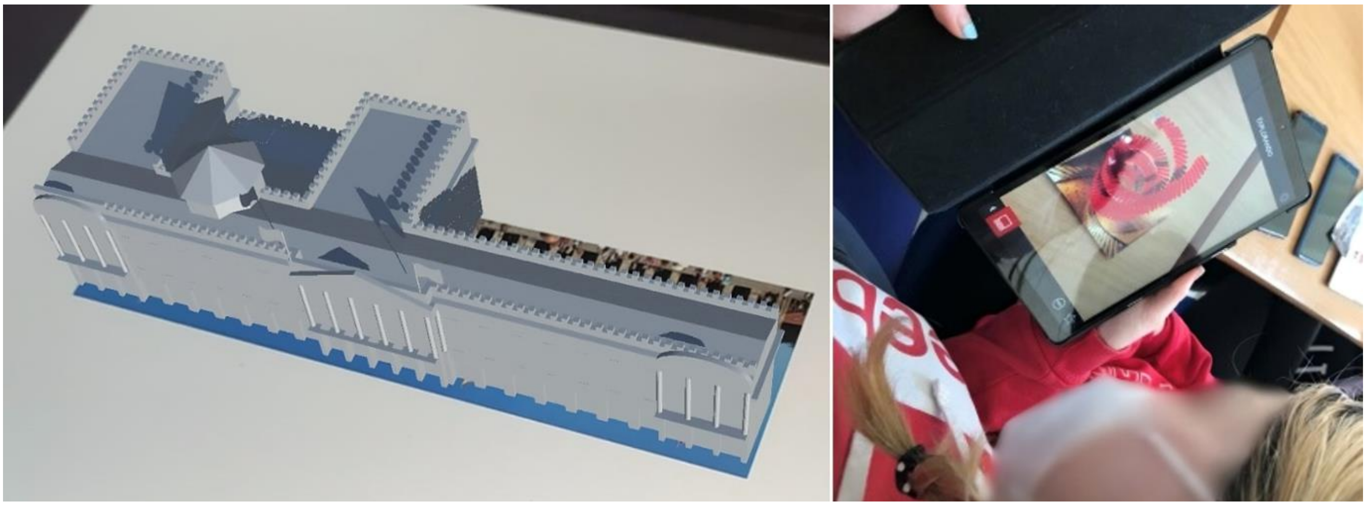

Figure 4. City Hall of Santiago de Compostela & triple-spiral staircase in augmented reality (Source: Authors' own elaboration)

Figure 5. Maps of way of Saint James & Santiago de Compostela with markers & printed figures (Source: Authors' own elaboration)

community *Aumentaty* and the *Scope* application for mobile devices (Fernández-López & Blanco, 2023).

Figure 4 shows the City Hall of Santiago de Compostela seen in augmented reality and the triple-spiral staircase built by Domingo de Andrade in the monastery of Santo Domingo de Bonaval. The designs were observed on tablets, which were made available to the students for this purpose.

Phase III (situating designs and markers on the map) aimed to make the final preparations for presenting the project to the public. Two maps were created: one of the French route of the way of Saint James and another of the city of Santiago de Compostela. Both the printed figures and the markers (photographs of the architectural elements) were put in the correct places, with the result shown in **Figure 5**.

RESULTS

This section presents the results obtained with regard to mediational and affective suitability. As far as mediational suitability is concerned, the tool based on SAMR model (Puentedura, 2012) was analyzed. As mentioned later, the analysis of affective suitability was broadened by studying the emotions and the correlations between them via the emotion questionnaire adapted to the context from Gómez-Chacón's (2000) mood map.

Mediational Suitability

Mediational suitability is an essential aspect of this proposal. As far as material resources are concerned, it can be observed that it was possible to introduce different representations of the intended mathematical objects, facilitating new languages (e.g., graphic), procedures (e.g., constructive solid geometry) and learning situations (in which the student is situated at the center of the processes, working with digital tools in collaboration with others). On the other hand, the decomposition, visualization, and properties of three-dimensional figures were contextualized using specific visual models, which made it possible to approach mathematical proof and concepts with a lower degree of abstraction as the first step towards the generalization of the target contents.

The other components of mediational suitability fit in a similar way with what has been established by Godino et al. (2023). The study aid, in this case the 3D design program, is presented from a critical perspective, making PSTs reflect on when and how to employ it. This is achieved on the level of didactic knowledge by the presentation of SAMR model and in relation to the use of an online platform, which requests a username for underage students, the safest way of using this resource in the classroom and monitoring the use children make of it. The number and distribution of the participants was appropriate, with 20 students working in pairs in each group. The timetable differed among the different groups, varying from 9:00 a.m. to 8:00 p.m. The time dedicated to the project was somewhat short and, as a result, some of the designs were finished as homework.

The activity can be situated in the Transformation layer of SAMR model (Puentedura, 2012) and, more specifically, in the redefinition stage. It is a project, which cannot be carried out without the use of 3D design and printing technology. This is accompanied by a substantial methodological change, which is worthy of note in that it situates the students at the center of the processes and presents a new learning environment, which offers advantages such as ubiquitous and real-time access. It is notable that the cognitive processes required of the students are, in accordance with Bloom's taxonomy (Forehand, 2005), mainly of a higher order, with most of the project necessitating cognitive levels such as analyzing and creating.

Affective Suitability

Affective suitability constitutes the focal point of research in this study. The project, according to what is set out in Gómez-Chacón's (2000) mood map (which was adapted to the context of this study), is of interest to the students, with *curiosity* being the most frequently experienced emotional state. Situations are proposed, which make it possible to consider the usefulness of mathematics in everyday and professional life in contexts in which knowledge can be applied in a practical way. An example of this is the use of 3D Boolean calculations (union, split, intersection, and difference) with the aim of building a specific object. By situating students at the center of the processes, the project confers upon them the responsibility of carrying it out, taking part and making decisions throughout the process, thus fostering perseverance. Argumentation also has a crucial role to play as the students work in pairs and must reach agreements on how to achieve the desired figure. However, the freedom and responsibility given to the students demonstrates, according to the data of the questionnaire, a decrease in emotions such as *confidence* and a considerable increase in emotions such as *despair*. It should be noted that, upon finishing the project, several students admitted feeling surprised by the results obtained and confessed to having doubts throughout the process that they would be successful in their aims. This could strengthen students' self-*confidence* by setting them a challenge, which is not too far removed from their learning zone, but which requires some effort to finally achieve success.

The emotions experienced by the students were always taken into consideration by the teachers and by the students themselves as the research to be carried out was presented to them and they were asked to reflect on their feelings when completing the emotion questionnaire. The aesthetic qualities and the precision of the mathematics were particularly important as, for example, a deviation of 1mm in the alignment of the shapes employed could lead to the whole piece being wrong when it was printed in 3D.

Percentage study

This section analyses the affective responses obtained from the emotion questionnaire adapted to the context from Gómez-Chacón's (2000) mood map. For this purpose, two tools have been employed. On the one hand, a percentage study has been carried out, represented via a bar chart reflecting the number of students who claimed to have experienced each of the 14 emotions taken into consideration. On the other hand, a correlational study between the emotions experienced has been conducted. To interpret the correlational variables, the following criterion and color coding will be taken into consideration to facilitate the understanding of the data: Between zero and 0.10: non-existent correlation (uncolored cell); between 0.10 and 0.29: weak correlation (green cell); between 0.30 and 0.50: moderate correlation (yellow cell); and between 0.50 and 1.00: strong correlation (red cell).

Figure 6 shows the percentage of students who claim to have experienced each of the emotions considered in the questionnaire adapted from Gómez-Chacón's (2000) mood map. The graph shows the greater presence of pleasant emotions with blue bars (*curiosity*, *cheerful*, *confidence*, *just great*, *amusement*, *liking*, and *calm*) than of less pleasant emotions, represented with pink bars (*bewilderment*, *boredom*, *hurry*, *blocked*, *brainteaser*, *despair*, and *indifference*). The most commonly experienced emotions were *curiosity* and *cheerfulness*, although a large percentage of students claim to have experienced the *brain-teaser* emotion. It can also be observed that there is a very low presence of emotions relating to *boredom* or *indifference*, in addition to the emotion *calm*.

Emotional correlation

This section presents the results obtained for the correlational study between the different emotions recorded. As there were two dichotomous variables, Spearman correlation coefficients were calculated for each of the emotions considered. The results obtained from the two-tailed significance test are also presented,

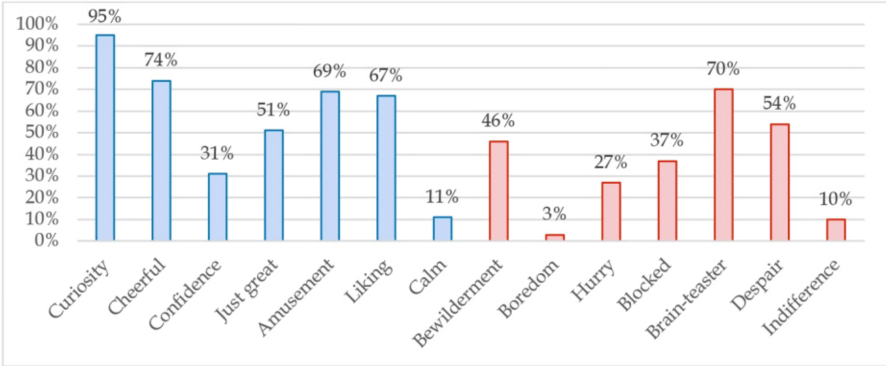

Figure 6. Graph of data collected from emotion questionnaire for phase (I): Creation & printing of 3D designs (Source: Authors' own elaboration)

		Curiosity	Cheerful	Confidence	Just great	Amusement	Liking	Calm
Curiosity	Correlation Coefficient	1.000	.234*	137	.211*	.205*	.296**	-71
	Sig. (2-tailed)	.	20	179	37	43	3	485
	N	98	98	98	98	98	98	98
Cheerful	Correlation Coefficient		1.000	.338**	.363**	.595**	.341**	91
	Sig. (2-tailed)		.	<.001	<.001	<.001	<.001	374
	N		98	98	98	98	98	98
Confidence	Correlation Coefficient			1.000	.518**	.334**	.321**	.328**
	Sig. (2-tailed)			.	<.001	<.001	1	<.001
	N			98	98	98	98	98
Just great	Correlation Coefficient				1.000	.393**	.362**	142
	Sig. (2-tailed)				.	<.001	<.001	162
	N				98	98	98	98
Amusement	Correlation Coefficient					1.000	168	188
	Sig. (2-tailed)					.	98	64
	N					98	98	98
Liking	Correlation Coefficient						1.000	16
	Sig. (2-tailed)						.	878
	N						98	98
Calm	Correlation Coefficient							1.000
	Sig. (2-tailed)							.
	N							

Figure 7. Correlation between pairs of pleasant emotions for phase I (Source: Authors' own elaboration)

along with the correlation between pleasant and less pleasant emotions. The results are divided into three differentiated parts according to whether they are correlational between pairs of pleasant emotions, between pleasant and less pleasant emotions or between pairs of less pleasant emotions.

Figure 7 shows the correlational values obtained between pairs of pleasant emotions. As can be observed, of the 21 cases considered, eight have a moderate correlation (with significance indices of less than .001 in all cases except one) and two have high correlations with significance indices of less than .001 (*confidence-just great* and *cheerful-amusement*).

The correlation obtained between pleasant and less pleasant emotions is shown in **Figure 8**. Of the 49 cases considered, only six have a moderate correlation (with significance indices of less than .001 in all but two cases), most of them presents weak correlation and there are none with a strong correlation.

Figure 9 shows the values obtained for the correlation between pairs of less pleasant emotions. No moderate or strong correlations can be observed between any of the 21 cases considered. As can be seen most of the cases show weak correlation under .295.

DISCUSSION

The data collected in the percentage study, presented in **Figure 6**, show the following descending progression in relation to the presence of the emotions recorded: *curiosity*, *cheerful*, *brainteaser*, *amusement*, *liking*, *despair*, *just great*, *bewilderment*, *blocked*, *confidence*, *hurry*, *calm*, *indifference*, and *boredom*. As can be observed, in general, mainly pleasant emotions were recorded, which would suggest that the project was enjoyable and satisfactory

		Bewilderment	Boredom	Hurry	Blocked	Brain-teaser	Despair	Indifference
Curiosity	Correlation Coefficient	91	-.263**	-110	-158	98	-190	66
	Sig. (2-tailed)	375	9	282	119	338	61	521
	N	98	98	98	98	98	98	98
Cheerful	Correlation Coefficient	-153	-.304**	140	-.365**	-59	-.304**	-.219*
	Sig. (2-tailed)	132	2	170	**<.001**	562	2	30
	N	98	98	98	98	98	98	98
Confidence	Correlation Coefficient	-181	-118	2	-.289**	-21	-.232*	-.211*
	Sig. (2-tailed)	74	247	984	4	837	21	37
	N	98	98	98	98	98	98	98
Just great	Correlation Coefficient	-.265**	-181	-12	-.332**	58	-166	-113
	Sig. (2-tailed)	8	74	905	**<.001**	570	103	270
	N	98	98	98	98	98	98	98
Amusement	Correlation Coefficient	-107	-.274**	86	-.371**	-64	-.238*	-.336**
	Sig. (2-tailed)	295	6	401	**<.001**	534	18	**<.001**
	N	98	98	98	98	98	98	98
Liking	Correlation Coefficient	-86	-3	24	-176	138	-161	-.231*
	Sig. (2-tailed)	398	980	813	83	177	113	22
	N	98	98	98	98	98	98	98
Calm	Correlation Coefficient	-66	105	-99	-56	-19	-183	-124
	Sig. (2-tailed)	516	303	333	582	852	71	222
	N	98	98	98	98	98	98	98

Figure 8. Correlation between pleasant & less pleasant emotions for phase I (Source: Authors' own elaboration)

		Bewilderment	Boredom	Hurry	Blocked	Brain-teaser	Despair	Indifference
Bewilderment	Correlation Coefficient	1.000	189	37	.238*	188	169	126
	Sig. (2-tailed)	.	62	719	18	64	96	217
	N	98	98	98	98	98	98	98
Boredom	Correlation Coefficient		1.000	27	.228*	-19	45	149
	Sig. (2-tailed)		.	789	24	855	661	144
	N		98	98	98	98	98	98
Hurry	Correlation Coefficient			1.000	-134	-132	-49	-31
	Sig. (2-tailed)			.	187	197	630	762
	N			98	98	98	98	98
Blocked	Correlation Coefficient				1.000	166	.295**	117
	Sig. (2-tailed)				.	101	3	252
	N				98	98	98	98
Brain-teaser	Correlation Coefficient					1.000	6	123
	Sig. (2-tailed)					.	950	228
	N					98	98	98
Despair	Correlation Coefficient						1.000	80
	Sig. (2-tailed)						.	432
	N						98	98
Indifference	Correlation Coefficient							1.000
	Sig. (2-tailed)							.
	N							

Figure 9. Correlation between pairs of less pleasant emotions for phase I (Source: Authors' own elaboration)

for the majority of the students. However, the presence of certain less pleasant emotions must be noted as they were expressed quite frequently. Indeed, seven out of ten students claimed to have experienced the *brain-teaser* emotion and one in two *despairs*. It should be noted that, in line with the ideas of authors such as Askham (2001), these results do not necessarily mean that 3D design is an undesirable resource on an emotional or skills-based level. On the other hand, it is often essential to experience less pleasant emotions (in due proportion). This does not necessarily lead to bad results within the teaching and learning process (Rebollo et al., 2014). The presence of such emotions could also be related to some of the reasons outlined below.

Authors such as Gil et al. (2005) associate *despair* and the lack of *calm* with the mental block, which often arises with activities involving problem-solving.

As Hodgen and Askew (2007) point out, this phenomenon could be due to students' relative lack of confidence regarding knowledge of the mathematical content required to resolve the task.

In our study, 31% of the students claimed to have experienced this emotion. It is notable that only 2% of the participants stated that they had had previous experience with 3D design programs. This finding highlights the relevance of the proposals of Ford and Minshall (2019) and the reflections of Fortuny et al. (2010) with regard to the need to begin preparing students from an early age and maintain their technological training over time in order for them to be able to confront emerging challenges in this field. Considering this perceived difficulty among the students regarding the task, it was observed how, unlike Picos et al. (2004), who found a two-way nexus between perceived difficulty and *boredom*, almost no correlation was found in the present study between these emotions (*despair* and lack of *calm*) and *boredom* (which only three out of 100 subjects claim to have experienced).

On the other hand, the significant presence of the emotional states' *brainteaser* and *despair*, as well as the low presence of *calm* and *confidence* could be due to the introduction of technology into the classroom. This introduction, which offers autonomy to the participants and places them at the center of the teaching and learning process, requires a certain capacity to resolve problems via strategies, which students do not commonly employ, with a large part of the formal evaluation of the proposal falling upon this phase (Caballero Carrasco et al., 2008; Kwon, 2017). The significant presence of these less pleasant emotions could be supported by the difficulty in altering states, which are so resistant to change, such as the beliefs students have about mathematics (Hodgen & Askew, 2007; Marbán et al., 2020). In spite of the above, it can be observed how all of the students, in relation to the results obtained in the evaluation rubric, carried out the tasks they were given satisfactorily.

The correlational analysis shows the highest correlational means were for pairs of pleasant emotions (**Figure 7**), with the lowest being for pairs of less pleasant emotions (**Figure 9**) and intermediate values for the correlation between pleasant and less pleasant emotions (**Figure 8**). From these results, it can be deduced that the achievement of certain pleasant emotional states has more of an influence on the predisposition to experience other similar emotions than do the less pleasant emotions among themselves. The correlational data show two strong correlations between pairs of pleasant emotions: *cheerful-amusement* and *confidence-just great*. They also show three emotions, which, in general terms, do not correlate with other emotional states: *calm*, *hurry* and *brainteaser*.

The highest correlation is *cheerful-amusement* (.595), followed by *just great-confidence* (.518). The latter correlation proves even more relevant if the differences registered in the percentage study regarding the number of students who claim to have experienced these emotions are considered. Once more, this confirms the theories of Ford and Minshall (2019), Fortuny et al. (2010), and Gil et al. (2005) regarding the need for initial and ongoing training for teachers as a tool to provide them with a sufficient degree of *self-confidence* to be able to teach successfully by enjoying what they teach. In a different sense, it leads to the conclusion that practices, which prove pleasant favor *self-confidence* in the processes. When comparing this information with the data of other studies considering the correlation between self-*confidence* and other emotions such as enjoyment or motivation (which would correspond here to the emotions *just great* and *cheerful*, respectively) quite similar results can be observed (Casas et al., 2016; León-Mantero et al., 2018; Nortes Martinez-Artero & Nortés Checa, 2020). This may indicate that the inclusion of technology (which often leads to a lower degree of self-*confidence* among PSTs due to a lack of training and the difficulties implied by its use) does not imply a decrease in the correlation of self-*confidence* with other emotions with regard to studies in which technology is not employed.

Cheerful is the emotion, which, in general terms, correlates most with the rest (both pleasant and less pleasant emotions). This could suggest that promoting practices, which encourage students can lead to significant changes on an emotional level in experiences, which combine mathematics with technology and, more specifically, with 3D printing. This is in line with the studies of Bieleke et al. (2023), Dickson et al. (2021), Kwon (2017), and Tejera et al. (2022), confirming that the use of 3D printing can lead students to experience other pleasant emotions. However, the research carried out by Cheng et al. (2020) does not show a significant correlation between the use of 3D printing and an increase in motivation.

Bursal and Paznokas (2006), Caballero Carrasco et al. (2008), Isiksal et al. (2009), León-Mantero et al. (2018), and Simpkins et al. (2006) have all highlighted anxiety as a common emotion in the teaching and learning processes of mathematics. These authors state that this emotion has strong negative correlations with regard to pleasant emotions such as *confidence* and *cheerfulness.* It should be noted that the present study does not contemplate the emotional state of anxiety as such. However, these results can be compared with the data obtained for anxiety-related states such as *blocked*, *despair* and a lack of *calm*. In this regard, a significantly lower correlation can be observed in the present study with values lower than -.365, which never prove to be significant. These results could indicate that the inclusion of 3D design and printing in the teaching and learning processes of mathematics can lead students to feel blocked, desperate, or lacking calm, confidence, and joy interchangeably, generating very different emotions and correlations between the students.

Finally, let us highlight the limitations of the study. First, due to the limited sample and time dedicated to this project, larger studies are required to corroborate and contrast the conclusions from the correlational analysis. In this sense, it would be necessary to expand not only the sample but also consider variables such as social context, age, or previous training/academic itinerary to reach verified results. Secondly, considering carrying out more activities with this tool for the same group of students can also help minimize variables related to aspects of the activity that have nothing to do with 3D design. On this basis, it would be beneficial to consider a longitudinal study to remove the newness variable from the resource. Lastly, conducting interviews could help obtain more information and corroborate some of the data obtained.

CONCLUSIONS

This study has focused on the emotions experienced by pre-service primary education teachers when approaching mathematical concepts via 3D design and printing in a contextualized STEAM project. 3D design is a tool with great potential for the learning of geometry as it facilitates the creation of interdisciplinary projects and experiences and promotes situated learning. In general, good results have been observed on both an affective and a mediational level.

The analysis of mediational suitability, based on SAMR model, has shown that the incorporation of 3D design and printing into a STEAM project on the way of Saint James pilgrimage route has required the redefinition of the mathematical tasks. This implies reaching the most advanced level of SAMR model in which innovative learning activities and contexts are generated, which would be unthinkable without the incorporation of the available technology. This represents a significant transformation with regard to the initial task.

As far as affective suitability is concerned, with particular emphasis on the emotional component, the project shows an incidence of pleasant emotions among the participants. There is a much greater presence of pleasant emotions than less pleasant feelings, with the most frequently experienced emotions among the participants being *curiosity* and *cheerfulness* and the least common *boredom* and *indifference.* It can be assumed that students were curious about the activities and were motivated to carry them out. These emotions were reinforced by the low percentage of students who experienced *boredom* and *indifference*.

The correlational analysis conducted concerning the emotions recorded shows that the link between emotions is stronger between pleasant emotions than between less pleasant ones and that *cheerful* correlates most with the other emotions. This may suggest that favoring practices, which motivate students can lead to positive emotional changes in experiences, which combine mathematics and 3D printing. The results encourage reflection on PST training in terms of mathematics and technology, considering initial and ongoing training to be an essential tool for providing teachers with the self-*confidence* required to successfully teach mathematics on the basis of enjoyment of the subject and the resources employed.

Some less pleasant emotions, such as *brainteaser* and *despair* were also observed with considerable rates of frequency. Surprisingly, these did not automatically translate into negative aspects for the learning process. This suggests that the introduction of technology causes different emotional reactions in different people, generally leading to pleasant experiences. However, in some cases, it can trigger less pleasurable emotions related to anxiety.

Looking to the future, possible studies could consider as well PSTs to design and implement practices with 3D design at basic education contexts to analyze their didactic-mathematical knowledge. Likewise, focus could be placed on analyzing the suitability of using 3D design in relation to other facets of didactical suitability such the epistemic or cognitive ones.

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