Tangible 3D Printed Workshop for introducing Art and Creativity in Engineering Drawing Subject.

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Abstract. In studies of engineering, creative competence is becoming more and more important. In order to develop this ability, a three-dimensional modelling workshop called STELLA 3D was designed in collaboration with teachers from fine arts studies, based on the pictorial work of Frank Stella. In this article, a tangible version of this workshop is presented, printed in 3D, which was tested during the 2016-2017 academic year by 31 students in the First Year of Engineering at the University of La Laguna. The data obtained from the experimental group show that the students have increased their creativity values in comparison with the Pre-test, going from a score of 93,8 to 132,0. The resource developed in this work includes QR codes, which enable digital files of the pieces for 3D printing to be downloaded, and makes it possible to replace them in case of loss or breakage.

Keywords: Creativity, Art, Space Skills, Standardized Views

1 Introduction

In the subject of Graphic Drawing in Engineering, one of the content to study is the relationship between three-dimensional objects and their standardised views in two dimensions. For the learning of subjects related with concepts of a three-dimensional nature, the use of traditional teaching resources in 2D such as books, plans or drawings may be insufficient for the spatial understanding of the students, which requires them to imagine objects with different orientations, to handle three-dimensional models and mentally transfer drawings between representations in two and three dimensions.

For this reason, in educational environments, the use of tangible objects or models as a complementary teaching resource is normal and there are authors who indicate the model as a teaching element of the first order [1]. In engineering and architecture, it is common to use models, in geography, relief maps are used, in engineering drawing metallic pieces which can be handled are used and in artistic studies it is normal to use three-dimensional replicas of sculptural works, to name just a few examples in higher education at university level. In pre-university teaching, it is also usual for students to make their own models as just one more step in the learning process [2].

The use of these tangible models presents certain drawbacks such as the price, breakages, loss, difficulty of movement, storage, access, etc. These factors place limits on the use of a wide variety of tangible models as learning objects. The lack of access to the tangible objects is especially evident in online education.

In order to solve these problems, the use of 3D digital models is a feasible option, as they are easily accessible from ICT resources such as the Smartphone, tablets or computers, and they also make three-dimensional handling similar to the tangible model possible. However, Álvarez [1] makes the importance of models as an educational resource clear. In this sense, the lowering of prices in digital manufacturing technologies such as 3D printers makes it more and more possible to add tangible learning objects to standard formal teaching.

In adidtion, the current higher education curriculum is designed based on the acquisition of skills. The European Commisssion defines the term "competence" as the proved capacity to use knowledge and skills. Knowledge is the result of the assimilation of information which takes place all along the process of learning. Skill is the ability to apply knowledge and to use techniques in order to complete different tasks and to solve problems. According to the swiss sociologist Ph. Perrenoud [3], competences allow to face a complex situation, to build a suitable answer. As a result, the student will be able to produce an answer which has not been previously learnt.

Solving problems creatively is a generic skill that appears in engineering degrees. The definition and classification of competences in the European Space for Higher Education is based on the Tuning project [4]. This project includes, as a generic competence, the ability to generate new ideas (creativity) and in spanish universities is listed in the White Papers of Engineering Degrees [5]. The importance of creativity in engineering education is an increasingly important aspect in many countries although not yet a widespread approach [6].

In this article, the creation and validation of a three-dimensional tangible educational resource is described for the boosting of creativity, the Stella 3D Tangible Puzzle. This resource is the evolution of a 3D modelling workshop called Stella 3D, developed to encourage creativity, spatial skills and the learning of standardised views. The resource developed in this work includes QR codes, which enable digital files of the pieces for 3D printing to be downloaded, and makes it possible to replace them in case of loss or breakage.

2 Background

2.1 Creativity in engineering education

Institutions such as The National Academy of Engineering in the U.S.A. in its strategic report The Engineer of 2020 [7, 8], says that Humanities and Social Sciences, Communication and Presentation skills are more, or at least as, important as the technical knowledge for a professional engineer. Precisely, in this particular report, it is said, “It is appropriate that engineers are educated to understand and appreciate history, philosophy, culture, and the arts, along with the creative elements of all these disciplines”. Furthermore, creativity should be an integral part of the engineering design process [9, 10] understanding this activity as the process that culminates in the proposal of new products. As Howard says [11], in many situations there is no clear differentiation between the production and development of ideas and the production and development of products.

Due to this, schools should not continue teaching isolated disciplines, but move forward towards a Human-Centered Education. Science, Technology, Engineering and Mathematics (STEM) should include Art and Design to favor creativity alongside with reasoning and therefore, tend to a new acronym to make STEAM (“A” is for Arts and Design). This new concept emphasizes the long term thought for professionals of engineering because it takes into account the fact that the world has moved onto a phase of continuous change where they have to be constantly adapting to new working realities [12].

It has been a traditional thought, that studies of Humanities and Fine Arts were considered important for engineering students because they made them more complete people. That is, Arts were understood as a complement for an engineer, as a way to balance those very technical studies with disciplines, which were far away from such a deductive approach. However, nowadays it is beginning to be accepted that Liberal and Fine Arts do not only get more balanced people, but also better engineers. This is so because the previously mentioned disciplines work with ambiguity and with those inductive methods that were not used traditionally in technical studies. This holistic approach of learning allows the possibility to face with more guarantees, a world where deduction is not always the most appropriate intellectual tool because everything is changing so much and new objects have to be created. It is important to remember that engineering, in essence, is an act of creation and creation is always the expression of imagination [13].

Creativity in engineering education is an increasingly important aspect in many countries although not yet a widespread approach [6]. For example, in year 2009, the Massachusetts Institute of Technology (MIT) employed the writer Junot Diaz, 2008 Pullitzer Prize for Literature, to teach creativity to engineers [14]. Experience showed that although initially, some students thought that the experience was ridiculous, at the end of the semester they defended the importance of the arts in their learning as engineers. In 2010, Syracuse University gave a seminar that brought together architecture and structural engineering students. The main objetive of the overall project was to find strategies to promote and reward creativity in engineering students. It was demostrated that althought engineering students initially expressed frustration with the open-ended assignments, at the end of the project, they began to show interest in achieving aesthetic results [15].

From 2011 to 2013, engineering undergraduates from the Valparaiso University College of Engineering (Valparaiso, Indiana, USA) participated in a four-day off-site course focused on creativity. They use pre- and postcourse surveys to meassure some parameters about the students' understanding of the roles of creativity in engineering Studies [16]. In 2014, the University of Alabama, USA, conducted an experience introducing creativity in freshman students of electrical and computer engineering studies [17]. The goal of this project was to be conscious of creativity in the design process and to think about problems in an open-ended manner. Students perceive exercises difficult but motivating and therefore showed greater involvement in engineering studies from the first year.

So we can conclude, that at this point, as suggested in the Changing the Conversation report [18] creativity must go beyond a mere concept, and must be incorporated into engineering curricula [19].

2.2 Stella 3D workshop

Before starting to design a workshop to promote creativity, the Development of Spatial Skills Research Group (DEHAES) at La Laguna University in Spain, since 2004, has made several workshops and tools focusing on the development of spatial abilities in engineering students [20]. These tools, ease the understanding of the concepts and the relations between two and three-dimensional representations.

All these workshops and tools have been implemented in the subject of Engineering Graphics, due to the fact that it is a subject whose contents and activities have been traditionally used to develop students' spatial skills. One of the working guidelines is based on the use of commercial software, easy to implement and low cost, for 3D modeling, that is SketchUp [21]. This workshop has undergone several improvements lately, among them, the possibility to classify exercises according to the level of difficulty, to personalize the working template and to create a web site "Anfore3D.com" [22] where it is offered to our students a wide range of exercises. This 3D workshop was not only validated as a tool for developing spatial abilities [23], but also was validated for learning normalized views [24].

At this point we wonder if this methodology could be use in other studies, apart from engineering. That is the reason why a decision was taken, to move this experience to Fine Arts. Therefore, during the Academic year 2010-2011, the same workshop was carried out on that subject and we may say that the results and the acceptance on behalf of the students of Fine Arts was quite favorable [24].

It is important to point out that the 3D workshop has been thought from the point of view of orthogonal projections where each exercise usually has just one solution. The process of 3D modeling allows students to explore their own way so as to find a solution, but the fact that it has only one, limits their own creativity. In an artistic environment, problems with a single solution are not the most common ones, because exercises, in general, are more open and let students explore multiple options, being all of them correct.

Although creativity has not just a single definition, there is general agreement that, whatever it is that we mean by creativity, it involves gathering things (words, images,...) in a novel way. There is also consensus that some types of creativity, involve the ability of divergent thinking (generating multiple solutions to a problem), as opposed to convergent thinking (one solution) [6].

To complement this creative aspect, we decided to develop a new workshop on 3D modeling, using the same program (SketchUp with personalized templates), to carry out the understanding of the tridimensional space from the view of Fine Arts studies. The above-mentioned workshop was called Stella 3D because it is based on the series of paintings named "Irregular Polygons" by the American artist Frank Stella made up of 11 works of art, gathered in four chromatic variants. (I, II, III, IV). The workshop was carried out with Fine Arts students during the academic year 2011-2012. The aim of the workshop was to build a three-dimensional volume starting from a two-dimensional shape (Frank Stella paintings). To carry out the activity, students used their knowledge of graphical projections and descriptive geometry such as parallel projection and conic perspective.

Fig. 1. Frank Stella paintings in web site: www.anfore3d.com

The use of SketchUp allows the possibility to create volumes without almost any learning. To facilitate the achievement of activities, two templates were designed for each of the eleven paintings corresponding to the afore-mentioned series “Irregular polygons”. One of the templates was designed as an option to work with the painting as a top view of a 3D object and the other one as a front view. Within the templates, besides having as a reference the painting chosen by the student, there is also a working 3D grid to be used as an auxiliary element in the creation of the volume. The template allows different views of the work under different points of view (axonometric and conic) and visual styles (outlines, charcoal, edges…). Despite the fact that we start from the same statement, in which we are obliged to keep the original Stella painting by in a normalized orthogonal view, each student proposes a different tridimensional solution.

These templates are available on webpage: www.anfore3d.com. This settings developed by Research Group DEHAES at University of La Laguna, has several multi-platform, multi-support and multi-format resources intended for the teaching of analysis forms and its representation. Among the contents there is a line of creative workshop with open solution exercises. Within these we find Stella 3D workshop.

Once we checked the efficacy of the workshop with Fine Arts students [24], we decided to use this more creative workshop in engineering settings in order to include the "A" of STEAM in the curriculum. The subject of Engineering Drawings, where concepts of normalized orthogonal views associated to a 3D model have to be learnt, permits the possibility to include this new focus without any difficulty. Students do not need artistic knowledge, but the fact that the exercise uses the paintings of an artist and the fact that the activity has different solutions means a step forward towards the introduction of art and creativity in students of engineering.

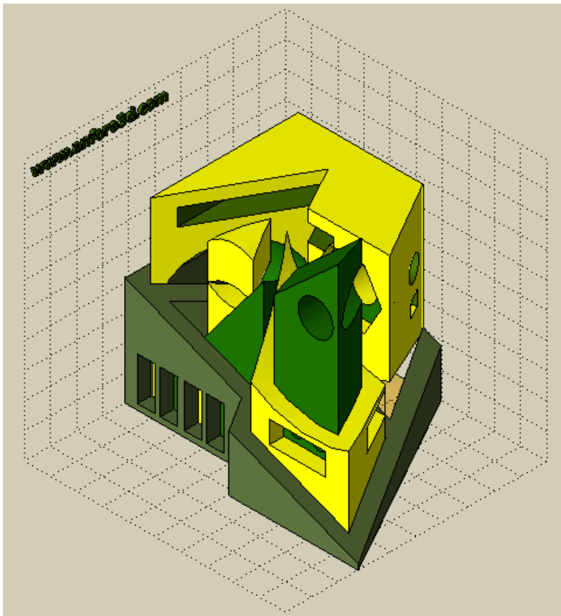

Fig. 2. Result of a Stella 3D workshop composition.

Therefore, with the Stella 3D Workshop, from the pictorial work of art by Frank Stella (Irregular Polygons), it is possible to teach traditional content from standardised views. What is more, the skills of spatial ability and creative competence have been incorporated (the capacity to produce or generate new ideas).

Despite the good results obtained, this workshop presents some limitations, such as the need for a computer to use it. Furthermore, as 3D digital modelling is used, the physical handling of the pieces is lost, which has been shown to be a useful learning method. The use of 3D printers allows the creation of educational resources in different areas (engineering, art, paleontology...) that encourage the manipulation of tangible pieces. [25, 26, 27]. In order to solve these limitations, a new module of this workshop has been created, which has been named the Stella 3D Tangible Puzzle. This workshop is oriented towards handling and sketching of the pieces.

3 Description of the Stella 3D Tangible Puzzle Workshop

The Stella 3D Tangible Puzzle workshop has, as its main objective, the handling and creation of compositions of three-dimensional pieces like a puzzle, as an experiment for promoting creative ability and the capacity for spatial vision. The creation of the Stella 3D Tangible Puzzle is a complementary option to working with standardised views, where the students make a three-dimensional composition from a two-dimensional pictorial work. In this case, within the paintings in the "Irregular polygons" series by Frank Stella, the Ossipee painting has been selected as the statement of the activity, (Figure 3). This work is made up of four shapes which fit into one another in four different colours. Each one of these shapes in different colours is going to be transformed into three-dimensional pieces, called A, B, C and D.

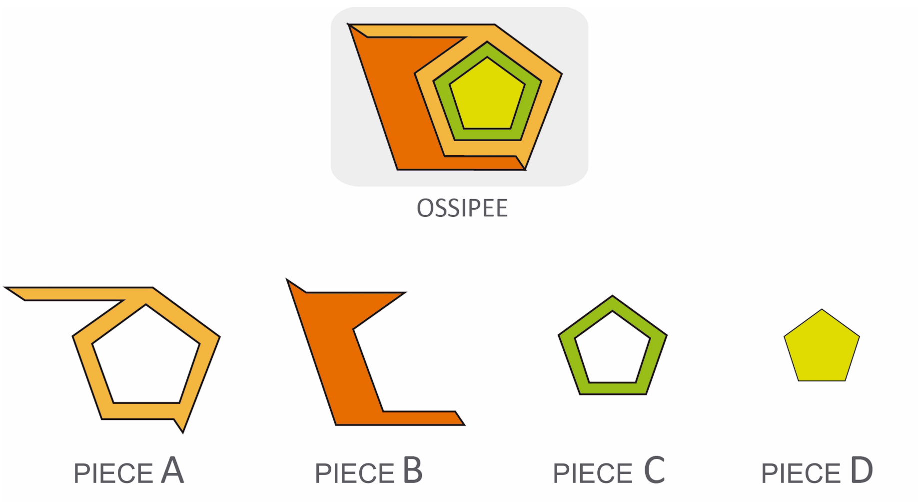

Fig. 3. Elements into which the Ossipee painting is divided

The Stella 3D Tangible Puzzle module, unlike the Stella 3D workshop described above, is a tangible educational material, where the pieces can be handled. Just like in the digital workshop, the upper part of each one of the pieces may be flat, sloping or curved. In this way, the compositions that can be made are the same as in the digital workshop. The final objective of this composition continues to be appreciating the original work by Frank Stella (Ossipee) when it is visualised from above (top view).

In order to carry out this workshop, a box containing twenty-six different pieces has been designed: six pieces of type A, six of type B, seven of type C and seven of type D. In turn, from each of the pieces four different finishes have been made; with a straight cut, an inclined cut, a curve and another one free, in such a manner that the view from above of each piece is not modified. Furthermore, some of the components are in two sizes, small and large (S and XL). The entire repository made up of these twenty-six pieces forms a set, and in this way it is possible to deal with a set of twenty-five students. With a single set, it is possible to create over 1500 different solutions. The objective is that the students should work in a group and should make several compositions with the pieces like a puzzle, so as to subsequently make the top view, the elevation and the profile and the isometric perspective by hand on some cards supplied for the exercises. In figure 4, you can see the top view and elevation of the figures that make up a set. It can be verified that several of the pieces share the same top view, regardless of the shape of the upper side. There is one additional piece, called "Base" which serves as the base on which to set up the puzzle with the solution selected by the student.

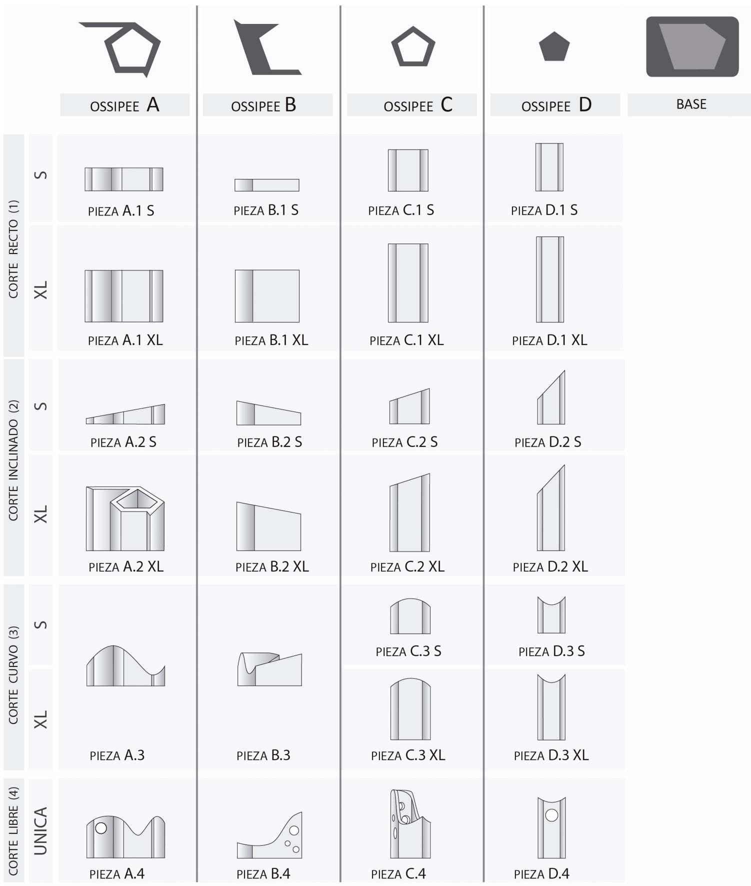

Fig. 4.. Set of pieces (Top and front view) which make up the Set of the Stella 3D Tangible Puzzle. .

The pieces are complemented with some cards on which the students have to make a sketch of some standardised views. In Figure 5, it is possible to see the box with a complete set of twenty-six pieces, to carry out the activity of the Stella 3D

Tangible Puzzle. In the image, it is also possible to see the paper cards for doing the exercise proposed.

Fig. 5.. Elements which make up the Stella 3D Tangible Puzzle workshop.

In order to solve the possible breakages or losses of the pieces of the Set, the box includes a QR code which gives access to the digital files of each of the pieces, available at a repository in the cloud. In this way, it is possible to replicate the complete set using, for example, a 3D printer.

4 Materials and methods

4.1 Participants

This activity took place at the University of La Laguna during the 2016/17 academic year with thirty-one students of the subject of Engineering Drawing from the first year of Engineering. The students were separated randomly into two groups, the experimental one (19 students) and the control one (12 students). The experimental group did the Stella 3D Tangible Puzzle workshop and the control group did not do this activity, but they made traditional paper and pencil exercises.

4.2 Software and Hardware

In order to carry out the activity, it is not necessary to use a computer, with the result that it can be done in a normal classroom. Large tables or desks are recommended to be able to draw the sketches. The material necessary to be able to carry out the activity is a Set of pieces of the Stella 3D Tangible Puzzle for every twenty-five students and the paper cards where the students will carry out the activity.

4.3 Measurement Tools

In order to measure creativity, the Abreaction Test for Evaluating Creativity, TAEC [28], by Saturnino de la Torre was used. This test can be applied from pre-school to adult. This one was chosen ahead of all possible other tests due to it being a graphical and inductive test of the completion of figures, which is very suitable for use in the context of the subject of Graphic Expression by Engineering students.

For the conduct of the TAEC test, it is only necessary to have a card including drawings of the basic figures of the test. One card per student is given out where he/she must fill in his/her details, the time the test commences and the time of completion. The student has complete liberty to draw on this card whatever comes into his/her mind starting from the basic figures given whether in graphite pencil, or coloured pencils or in biro.

4.4 Methodology

For the conduct of the test, three sessions were used for a total of four hours. In the first session of one hour, the creativity value with which the students started was measured. For this purpose, each student was given the TAEC test and they were given the necessary instructions to carry it out.

In the second session, of two hours, each student is given the card or cards where they must draw the standardised views and the perspective of the composition that they are doing. Then, the students begin to choose from the twenty-six pieces in the Set the four that they need to make their composition following the original shape of the Ossipee painting. When they have their composition finished, they make the standardised views and the perspective of the composition obtaining results like that in Figure 6.

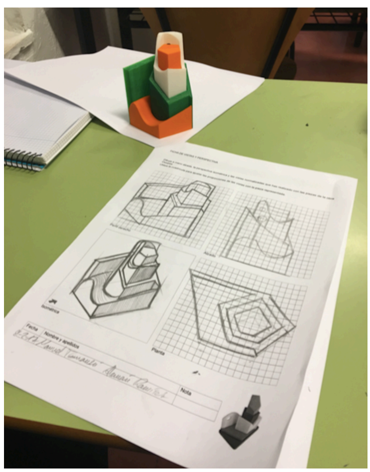

Fig. 6.. Exercise carried out by a student

The third and final session, of one hour, consists of again giving the students the TAEC creativity test.

5 Data analysis and results

In Table 1, it is possible to see the results obtained from the creativity test before and after the experiment, which are as follows. It should be pointed out that the range of scores in the TAEC test goes from 0 to 324 points. In order to determine the variation of the mean values of creativity, a Student's T test has been carried out where the null hypothesis is that the averages do not improve. In this way, for p values of less than 0.001 the null hypothesis is rejected and for greater values it is accepted.

Table 1. Treatment and Control Group Abreaction Test for Evaluating Creativity results

Abreaction Test for Evaluating Creativity (TAEC) results			
	Pre-test Mean Score (s.d.)	**Post-test** Mean Score (s.d.)	***p*-value**
Grupo Experimental (N=19)	93,8 (28,13)	132,0 (45,50)	0,00077223
Grupo de Control (N=12)	92,8 (40,67)	96,2 (47,76)	0,7785

6 Discussion and Conclusions

The data obtained from the experimental group show that the students have increased their creativity values in comparison with the Pre-test, going from a score of 93.8 to 132.0. This increase of 38.2 points is considered significant as in the Student's *t*-test a p-value of 0.00077 was obtained.

In the control group, the creativity values went from a score of 93.8 to 96.2 with a gain of 2.4. This increase is not considered significant as in the Student's *t*-test a p-value of 0.7785 was obtained.

For the purpose of comparing these results, it is possible to use as a reference those obtained in a previous experiment, carried out during the 2015/2016 academic year by Engineering students. In this test, a mean of 139.20 points in the TAEC test was obtained [29], which was very similar to the result obtained by the experimental group described in this article. In this case, the students carried out a creativity test based on the creation of personalised articulated dolls. On the other hand, in this same academic year 2016/2017 another experiment was carried out with Master's students who carried out a creative activity based on the creation of tangible earth models [30]. In this experiment, it was observed that the increase obtained was of 18.4 points, less than the result obtained in this experiment. The mean of the Master's students is lower, with a mean score of 102.8 being obtained.

Besides, with the results obtained in this research, and according to Sardá [2], the use of tangible elements is a useful strategy for the development of competences and learning, not only at pre-university levels but also at university. For this reason, in educational environments at university level, the use of tangible objects or models as a complementary teaching resource could be stimulated [1]. One way to stimulate the use of these tangible objects is to use 3D printers, because they solve some problems such as the price, breakages, loss, difficulty of movement, storage, access, etc... [25,26,27].

Therefore, with this Stella 3D Tangible Puzzle workshop, creative ability is boosted among the students without need of technological support, obtaining results that are comparable with those from previous experiments. Additionally, it is interesting to note that the box itself, in which all the pieces are, includes a link using a QR code which gives access to the digital files on each of the pieces (goo.gl/BGHZTq). In this way, it is possible to replicate the complete set using, for example, a 3D printer.

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