sustainability

MDPI

Article

Enhancing Creative Thinking in STEM with 3D CAD Modelling

Carlos Carbonell-Carrera *, Jose Luis Saorin, Damari Melian-Diaz and Jorge De la Torre-Cantero

Departamento de Técnicas y Proyectos en Ingeniería y Arquitectura, Universidad de La Laguna, Calle Padre Herrera, s/n, 38200 San Cristóbal de La Laguna, Santa Cruz de Tenerife, Spain; jlsaorin@ull.edu.es (J.L.S.); dmeliand@ull.edu.es (D.M.-D.) jcantero@ull.edu.es (J.d.l.T.-C)

* Corresponding author: ccarbone@ull.edu.es

Received: 11 September 2019; Accepted: 28 October 2019; Published: 30 October 2019

Abstract: Creative thinking is an essential part of learning for sustainability, as recent studies indicate. Creativity enables the engineer to find solutions for the design of a new product or for the improvement of one already designed, to make it more sustainable. However, currently, engineering education does not usually assess academic performance in terms of creativity, and although interest in creative processes in engineering is growing, its implementation in the classroom is still scarce. In the present study, a creativity workshop was conducted in order to find multiple solutions to the problem posed, in accordance with divergent thinking. The workshop was based on a 3D CAD modelling activity, and the students needed to give different 3D design solutions starting from a two-dimensional shape. The participants were 72 engineering students from the engineering graphics subject in the degree in agricultural engineering and rural areas. Nine different creative components were evaluated. That way, not only was a generic measure of creativity obtained, but it was also possible to know the evolution of the student after the workshop for each of the components of creativity separately. The results of the workshop confirmed that creativity could be enhanced, and therefore, the learning process for sustainability can be improved in engineering.

Keywords: 3D modelling; Computer-aided Design (CAD), creativity components; engineering; divergent thinking

1. Introduction

There are studies that indicate that creative thinking is an essential part of learning for sustainability [1,2]. Engineering needs different, innovative and creative solutions for a world in constant change. Creativity is an important tool in the search for a more sustainable future, directly linked to innovation and creative problem solving, claimed Hopkins [3], UNESCO chair in Reorienting Teacher Education to Address Sustainability. A creative engineer is able to find different solutions for the design of a new product or for the improvement of one already designed to make it more sustainable. Creativity facilitates offering different solutions in a useful and novel way [4–6]. Other authors [7,8] define this term as "general creativity". In a stricter sense, "creativity in engineering" is understood as a way of thinking that brings new ideas which are original and easy to apply in a functional and practical way [9,10]. Other authors [11] call "functional creativity" the novelty of needing to satisfy functional requirements, through the combination and connection of ideas in new ways.

Engineering and creativity, therefore, have a close relationship. Some authors even think that, "If engineers are not creative, they are not engineers" [12] (p. 22). Creativity is a necessary engineering skill, so engineers have a wide field for the support of creative skill development. Nevertheless, engineering education does not usually assess academic performance in terms of creativity [13]. That can be explained from the perspective that the teaching staff, and in particular the engineering professors, are not used to incorporating creativity in the teaching-learning processes or in evaluation [14–16]. Zappe et al. [16] found that, in a six-year period, only 16 articles related to creativity or the creative process appeared in the top five journals on engineering education. Another author concludes that, although students consider creativity to be an important factor in engineering, they do not have the perception of having improved their creative abilities during their university studies [17]. Although interest in creative processes in engineering is growing, its implementation in the classroom is still scarce [10,18–21]. This has, however, been done in fields such as science and language [22–24].

Saorin et al. [25] (p. 188) claimed that "it is necessary, therefore, to incorporate and stimulate creativity in the training of engineers, through activities, strategies and teaching methodologies that can develop this skill, to respond to a society that demands creative skill profiles for the challenges of a constantly changing world." Scott et al., [26], in a 70 study meta-analysis, found that creativity training was successful in training programs at different educational levels. Both general creative skills and the field of creativity in engineering can be enhanced with training [27,28]. Although, as discussed before, engineering education does not usually assess academic performance in terms of creativity, there are experiences in the field of engineering that invite the promotion of activities focused on the development of creativity.

In the present study, a creativity workshop was proposed in order to find multiple solutions to the problem posed, according to divergent thinking, in which there were open-ended activities, problem finding, and a variety of solutions together in an original way. That is to say, all those components considered by Shah, Smith and Vargas-Hernandez [29] to be vital towards enhancing the analysis and synthesis of information learned. The workshop was based on 3D modelling with computer-aided design, and the participants needed to build a 3D volume starting from a two-dimensional shape. There was not only one solution; each student proposed four different 3D design solutions. 3D modelling and design is essential for creativity, innovation [30] and problem solving [31,32]. When an engineering student designs something new, creativity should also be evaluated in addition to functionality, novelty and usefulness. In that manner, through practice, engineering students can learn to be more creative and contribute to innovation in their work environment [33]. Computer-aided design (CAD) is an information and communications technology (ICT) tool that can improve innovation because it allows the student to generate multiple and alternative ideas, and it has been used in educational programs to increase creativity [33,34].

This workshop was previously conducted in several engineering degrees in order to develop spatial abilities and learn normalized views [35], and it proved to be a valid tool for those purposes. The present research is a continuation of that work, in which a group of 72 engineering students (45 belonging to the treatment group and 27 belonging to the control group) participated in the workshop, and the impact on the development of their creative skill was studied. These participants studied the subject of engineering graphics of the degree in agricultural engineering and rural areas, a degree linked to the field of sustainability. Additionally, students carried out a Likert scale survey to express their opinions on the workshop.

Therefore, in this article, aspects of creativity in engineering are detailed, such as in professional and educational contexts, where creativity is used as an academic achievement predictor, as well as a tool for the measurement of creativity. Next, the Stella 3D workshop carried out with engineering students is described, along with the results obtained and the conclusions reached.

2. Creativity in Engineering

The ability to participate in a creative process to solve a problem or design a novel artefact is needed for engineering, especially for future engineers [36]. The world is moving towards a phase of continuous change in which engineers must adapt to changing circumstances and requirements. Engineers' decisions about design and innovation will, therefore, have important economic implications, and the future success of the economy will depend on the design-inspired innovation [37]. Moreover, creativity is an essential part of learning for sustainability [1,2]. Institutions such as the National Academies and the government of the United States demand innovative engineers to “drive the engine of America´s economy” [38,39]. Fernandes et al. [40] found that creative thinking is beneficial for product development. It is a fact, therefore, that engineers need creativity to be innovative, and academic institutions are already making efforts to produce creative engineers. Thus, through methodologies that evaluate creativity, teachers can measure it, and therefore, guide the training of students towards innovation in engineering.

In the aims of engineering education, the concept of creativity is beginning to be included into the curriculum, to highlight its importance in product design and problem solving [41]. This so-called creativity marketing can serve as a stimulus for creative individuals to enroll in engineering studies. At this point, as suggested in the Changing the Conversation report [42], creativity must go beyond a mere concept, and must be incorporated into engineering curricula [14].

The reasons for this late incorporation may be due to the fact that in engineering, the concept of "creativity" can be associated with the subjective and ambiguous [13], closer to the field of arts and humanities than to engineering. This has meant that students and teachers have not perceived creative abilities as a necessary part of an engineer's education. There are still engineers that believe “they are not creative people” [20]. From the perspective of the teachers, Cropley [14] and Zappe et al. [16] thought that the obstacle to deep integration of creativity in the classroom might be due to the discomfort of engineering teachers with assessing and teaching creativity, among other reasons, and the need to establish a coherent definition of creativity. Engineering students have perceived engineering as a technical implementation of ideas, rather than associating engineering with the idea-generation phases of design [41].

A change in the perception of engineering is, therefore, necessary, so that it may be perceived as a creative profession.

Currently, creativity has gone from being an accessory in engineering design to becoming a necessity. Numerous researchers demand creativity in engineering education as well as general education, [11,43–45]. And it is not only researchers: magazines like Time and Forbes [14] have recently published articles about the frustration of employers because the new graduates from universities lack creativity and problem-solving skills. Incorporating creativity into the engineering curricula will enable students to develop this skill that is so necessary in the engineering profession. From the student's perspective, engineering students already perceive creativity as essential to learning [33]. Surveys such as those conducted by Zampetakis, Tsironis and Moustakis, [46] showed that 87% of engineering students think that creativity is a necessary skill in their training. Moreover, 77% would like to receive a specific course on creativity and creative problem solving. These courses or workshops can develop creative ability through content, instruction and assessments made in an environment that targets creativity-focused learning goals [13].

Engineering creativity can be generated through divergent thinking (to generate multiple solutions to a problem) and/or convergent thinking (one solution) [10,47]. Guilford [48–50] was one of the precursors of the study of divergent thinking in creativity, defining it as a set of skills separated into two categories: transformational products (the ability to imagine changes, redefinitions, transpositions, revisions or modifications of existing information) and divergent thinking. Through divergent thinking we are able to generate logical alternatives based on the given information, whose importance is evaluated according to the variety, quantity and relevance of the product generated from the same source [51,52]. The present research is based on divergent thinking.

Hence, as an example, when focused like this research on divergent thinking, Chen, Jiang and Hsu [53] found an improvement in divergent thinking skills through carrying out research on creativity with engineering students. Seng [54] in his research, focused on a project based learning (PBL) course on engineering students’ creativity, and concluded that the participants achieved significant gains in cognitive skills, like concept relationships and divergent thinking. In Syracusa University, MacNamara et al. [55] conducted a course with structural engineering students in order to study different strategies to promote creativity, using open-ended activities (to think in an open-ended way to resolve a problem). They concluded that, although at the beginning of the study the participants felt frustration with open-ended assignments, at the end of the research they began to be interested in achieving aesthetic results.

2.1. Professional and Educational Contexts

At different levels of educational and professional life, using creativity has become a reality over the last decade.

At the pre-university level, institutions such as the Council of Graduate Schools [56] have emphasized the importance of improving innovation and creativity in graduate students in the United States. In the professional field of engineering, the National Academy of Engineering in the USA, in The Engineer of 2020 report, highlighted the link between education in engineering and creativity [57,58]. In that report, engineering education was linked to creativity. In the American university context, there are increasingly more degrees related to creativity and sustainability linked to engineering. To cite an example, the creative sustainability Master's degree program at Aalto University provides a multidisciplinary creative learning platform in the fields of architecture, building environment, business, design, real estate and water management.

In the European context, the European Higher Education Area designs the curricula to be focused on the acquisition of skills and competences. It is a model in which teaching moves towards a human being model, and is not limited to isolated disciplines. Competence is defined by the European Commission as the proven capacity to use knowledge and skills. The Tuning Project [59] is the base document in which these competences and skills are classified in the European Higher Education Area, and includes the ability to solve problems creatively, in addition to generating new ideas, such as creativity. This skill is defined as a generic competence in engineering careers. In the Spanish context, where this study was carried out, creativity is a generic competence in 84% of the degrees in the white papers of degrees adapted to the European Higher Education Area [60,61].

In STEM disciplines (science, technology, engineering and mathematics) there is growing interest in including and enhancing creativity in formal teaching, and in ensuring that this constitutes an appeal to awaken and expand interest in these disciplines [62]. At the same time, there is also a tendency to consider the integration between STEM education and education for sustainability (EfS) in authentic and meaningful ways [63].

2.2. Creativity as an Academic Achievement Predictor

It is interesting to know, a priori, the abilities of the students regarding the different abilities contemplated in the curricula of the engineering degrees. For example, the spatial skills group of the University of La Laguna (http://dehaes.webs.ull.es) conducts a battery of spatial skills tests with the students at the beginning of each academic year. With the results of these tests, actions are planned to address possible deficiencies detected among students, implementing workshops, zero or fast remedial courses at the beginning of each semester. Additionally, these results serve as a predictor of academic achievement in subjects related to spatial skills, such as graphic expression and design.

Creativity, considered as a competence to be acquired, could receive the same treatment, and thus guide methodologies and strategies aimed at improving those aspects of creativity that need reinforcement. Regarding whether creativity can be an indicator of academic achievement, research carried out in educational psychology presents conflicting results. While some research [64,65] shows that creativity has a positive (though slight) relationship with academic performance, other work finds no relationship between academic performance and creativity [66,67].

In higher education, Daly et al. [13] concluded that educational programs did not evaluate the academic performance in terms of creativity. In the field of engineering, Atwood and Pretz [41] conducted an experiment with 85 engineering students who belonged to the 2015–2016 academic year in order to study whether creativity was a predictor of engineering student persistence and achievement. The data obtained from creativity measurement were not a significant predictor of the engineering students' average grades, which indicates that creativity is not stimulated or rewarded in the curriculum and therefore cannot be a predictor of a student´s grade. This result coincides with other research, which indicates that in most engineering education programs, creativity is not stimulated or rewarded [13,14]. It is time to change this trend, to include creativity in the curriculum of engineering students and evaluate it to see if, indeed, creativity can be an academic achievement predictor.

2.3. Creativity Measurement

It is necessary to have a tool to measure creativity in order to quantitatively evaluate this skill in engineering programs, as well as to be able to detect talented people. A quantitative measurement of creativity will provide the engineering educator with a value to monitor the student's progress within an educational program aimed at improving creativity [68]. The tools that quantify this kind of human skill are psychometric tests. The measurement of creativity through testing began in the Second World War. J.P. Guilford, a psychologist at the University of California, who was commissioned by the Air Force, was assigned to study how to select pilots who, in an emergency situation, would react in an original way that would save their own life and the plane. Currently, there are many studies about tests that allow the measurement of creativity and divergent thinking [69–72]. In addition to the tests in paper format, currently, there are new methods, using computer scoring and online testing [73,74].

However, with the aim of measuring creativity in engineering, there are a limited number of tests, and there is no consensus about the choice of a particular one. The MBTI (Myers Briggs type indicator), identifies 16 personality traits, but does not specifically evaluate creativity in engineering [75]. The Owens creativity test [76] was a test designed to assess creativity in engineering, but only for the machine and or mechanical related occupations, in which a series of mechanical problems are posed and the user proposes solutions. Although it works with divergent thinking, this test, due to its specificity, cannot be extended in a generic way to other branches of engineering. Furthermore, this assessment tool is not currently used. Another divergent thinking test was the Purdue creativity test, developed by Lawshe and Harris [77]. This test was closer to measuring overall creativity than to measuring creativity in engineering [10], and there are very few research results in which this test has been used. Similar to the Purdue creativity test is the creative engineering design assessment (CEDA) test, as well as Guildford´s [78] model of divergent thinking. It was developed and revised by Charyton et al. [33], and measures creativity using three components: originality, fluency (number of ideas) and flexibility (different types of ideas). Other researchers have not used the CEDA, since its authors intend to establish a convergent validation before dissenting this tool. Although previous research [9,10] suggests that the CEDA is domain-specific to engineering, future CEDA research is needed involving industrial engineers [33].

In the Spanish context, where this study has been carried out, there are four tests that have been used most. The battery creativity test of Guildford [50] evaluates components such as flexibility, sensitivity, fluidity, processing and originality. It is a test very focused on the evaluation of creativity using divergent thinking. The Torrance test of creative thinking (TTCT) [79] assesses originality, fluency, inventiveness, flexibility and penetration. The CREA test [80] is a test used most in clinical, organizational and educational fields, as well as in the field of art and advertising, and it only proposes a single measurement of verbal creativity, without considering components. Finally, the abreaction test for evaluating creativity (TAEC) [81] is a graphic-inductive test of figure compression; that is, to do it you have to make drawings. It has been used in several recent research articles with the aim of teaching engineering [24,25,60,82–86]. That is one of the tests that is most used; it is focused on graphic creativity and students do it through drawings. Those are the reasons why TAEC test was chosen for this experiment; it is the closest to the subject studied by the participants; that is to say, engineering graphics. As an inconvenience, it is important to note that its correction is very tedious [82], since you may need 30 min to correct a single test.

2.3.1. The Abreaction Test to Evaluate Creativity

This test is not intended to measure creativity as an attribute of personality, nor to offer a numerical coefficient similar to the intellectual coefficient. Its objective, focused on teaching purposes, is to help the teacher to value creativity from different angles by proposing categories that allow the differentiation of subjects. It is an instrument characterized by simplicity, brevity, economy of resources, easy application and comprehension, as well as adaptation to any age and level. It has a high motivating value [87]. The student feels interested in carrying out this test. It is a test that supplements the shortfalls of other tests [87,88] for the measurement of creativity. Some of these shortcomings are based on pre-established answers, having a time limit for the test, not taking into account the pace and style of work of the participants, and not encouraging unusual responses or drawing on immediate associations. Being an inductive graph test, it can be applied to subjects of different languages and cultures, and adapts to different levels of training because it lacks saturation in factors of semantic, symbolic and technical types. Its measurement can be taken as an activity with a playful meaning and can be performed as an activity of graphic expression. It is not necessary, in turn, that the instructor has previous knowledge about its realization, since it does not have specific instructions. Nor does it present problems for its realization, since the user has complete freedom in the way to carry it out. Only this instruction is given: "Test your creativity. Draw a picture with these figures. Take the time you need and indicate when finished" (Figure 1).

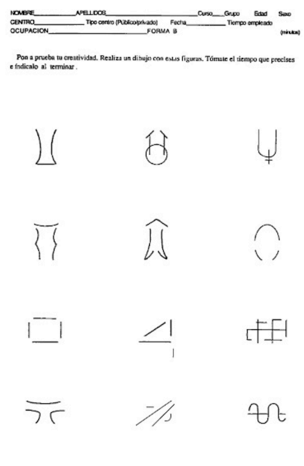

Figure 1. Test for evaluating creativity (TAEC) statement.

The abreaction test for evaluating creativity analyses nine quantitative factors: abreaction or resistance to closure, originality, elaboration, fantasy, connectivity (creative integration), imaginative scope, figurative expansion, expressive richness and graphic skills. There are two other variables, imaged morphology and creative style, but they do not provide a quantitative measurement like those mentioned above, but a qualitative one. For the evaluation of the test two criteria, two approaches are used: global (general creativity) and analytical. The overall assessment (or qualitative measurement) places the participant at a generic level of low, medium or high creativity. The analytical evaluation allows for the acquisition of a quantitative measurement of the results in each one of the components, in addition to offering a generic measurement of creativity, which is the average of the nine components. It is the analytical assessment used in this research, since it allows for comparisons and the detection of weaknesses and strengths of the individual in relation to creativity. The complete description of each of these components, as well as the assessment procedure, can be found in Carbonell-Carrera et al [85].

The test is presented on a sheet of paper with 12 unfinished figures, all of them on the same side of the page and distributed symmetrically in four rows and three columns. These twelve unfinished figures offer a total of 36 openings in different shapes and positions. Participants, starting with those 12 incomplete geometric figures, are free to draw whatever they want on the sheet. They can make a drawing with each one of them or make a drawing combining some of them or combining them all (general composition). Any of the following drawing tools can be used: pencil, marker pens, crayons, and in fact, anything else. In the test, each of the 12 figures is scored from 0 to 3 points for each of the nine components. Thus, 0–36 (3 × 12) points can be obtained for each component. Therefore, the total score of the test varies from 0–324 (36 × 9) points. "Specific instructions to evaluate each of the factors can be found in the Saturnino de la Torre's TAEC test description book [81]."

3. Method

At La Laguna University, where this experiment was performed, during the 2013/14 course, a workshop (Stella 3D workshop) was implemented in the subject of Engineering Graphics, focused on the development of spatial skills, which dealt with concepts such as normalized views and the relationship between two and three-dimensional representations [35]. In that workshop the students created 3D models from normalized views; thus, gaining training in concepts of graphic engineering, using SketchUp, a computer aided design (CAD) tool, and developing their spatial skills. In addition to measuring the development in spatial skills, students responded to a questionnaire on creative aspects and the importance of creativity in engineering. After the experiment, a second questionnaire was carried out to find out the students' estimations of aspects of creativity of the Stella 3D workshop. The results of the questionnaires showed that students considered creativity to be an important factor to working as engineers, and perceived that the Stella 3D was a useful tool to improve their creative competence (with results over 4 in a five points Likert scale), in addition to developing their spatial skills. But it was necessary to complete the study with a quantitative measurement of creativity, which is what is presented in this work.

3.1. Participants

The sample of this research was composed of 72 students (54 males and 18 females, from 18 to 19 years of age), from the degree in agricultural engineering and rural areas, belonging to La Laguna University. The 45 students (35 males and 10 females) of the morning shift of the engineering graphics subject were the treatment group that did the Stella 3D workshop. The 27 students (19 males and 8 females) of the afternoon shift did regular 2D exercises of normalized views, which have only one correct solution.

3.2. Procedure

Each student worked with one template (orthogonal view, standard view in plan (Figure 2), and had to model four different proposals from that template, following four different design criteria. (1) geometrical elements with all the upper sides being horizontal; (2) all the upper sides inclined; (3) all the upper sides curved; and (4) had to be a combination of the previous three.

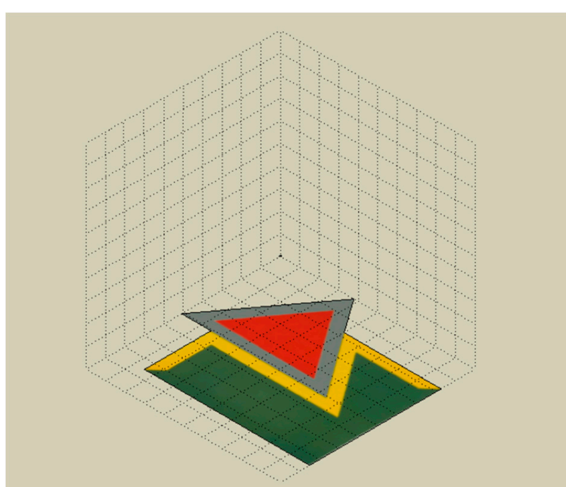

Figure 2. Template.

In the template a geometric figure with different colors was presented, based on a pictorial work of the famous American artist Frank Stella. The student had to transform these parts with different colors into 3D figures with the corresponding color according to design criteria 1, 2 and 3, as previously described. That is, they had to generate a 3D piece with the upper sides horizontal, another one with the upper sides inclined and another one with the upper sides curved. Each student determined the height of each 3D piece, the inclination of the cutting planes, the curvatures (concave, convex, radius of curvature, etc.) and could offer different solutions. The final 3D proposal was to assemble all the pieces into one, working with the concept of a component within an assembly. The fourth proposal was a combination of the three previous criteria designs. The workshop ran in two sessions of two hours, giving one hour for each of the design criteria. In Figure 3, one of the templates and the suggested solutions can be seen.

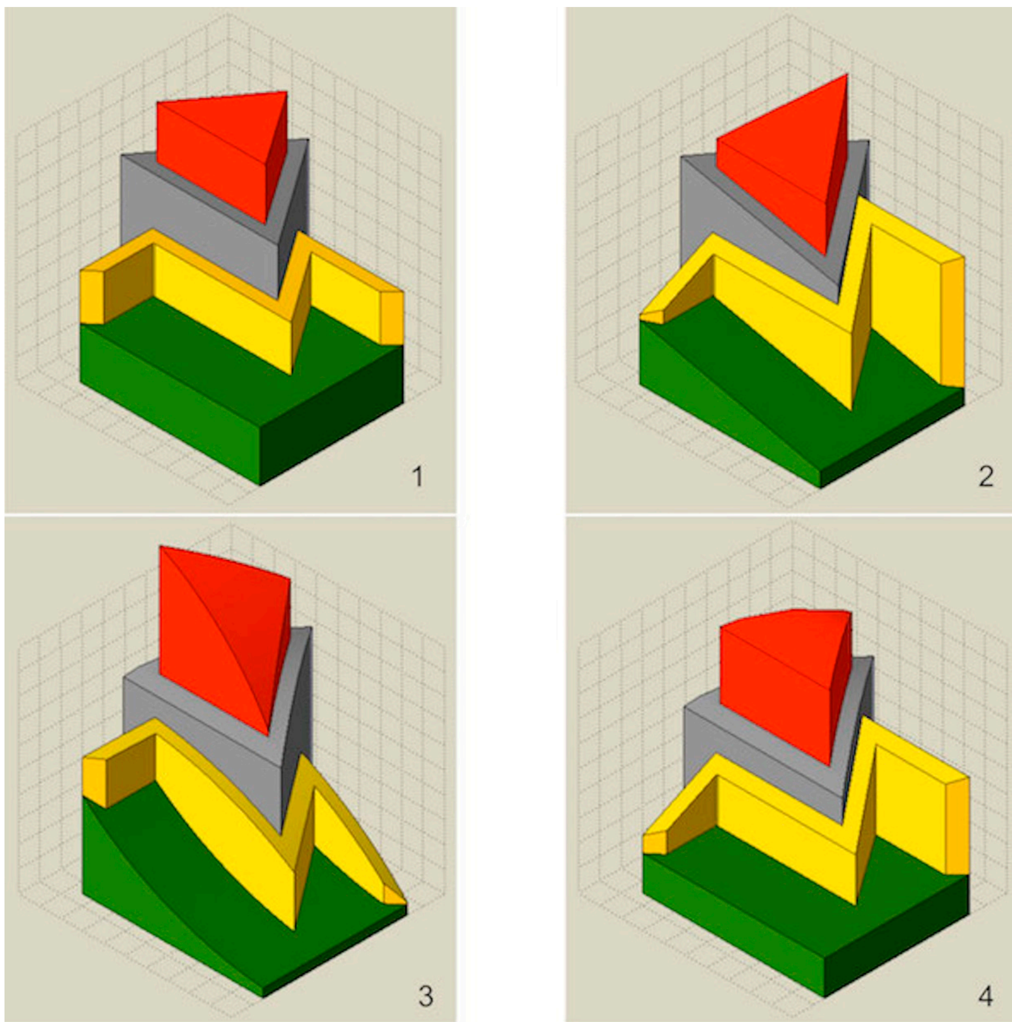

Figure 3. Example of four 3D different solutions given by a student.

The test worked, therefore, with engineering contents related to the management of geometry for the creation of sets of pieces (components), standardized views and 3D modelling in which the student demonstrated their ability to provide different solutions to the same problem (divergent thinking).

To measure the effect of the workshop on the creativity of the participants, students completed the abreaction test to evaluate creativity at the beginning of the semester (pre-test) prior to the workshop, and after it (post-test). The treatment and control groups had similar creativity values before participating in the experiment. The amount of time between the pre and post-creativity tests was six weeks. During this time, in addition to the Stella 3D workshop, the experimental and the control group did the normal activities of the subject. This test contemplates nine components of creativity, and the results are shown analyzing not only the increase in creativity, but also each of those components or factors. That way, not only was a generic measure of creativity obtained, but it was also possible to know the evolution of the student after the workshop in each of the components of creativity separately. The results were compared with values obtained in previous research with students of fine art, who, traditionally, have a greater predisposition to creative tasks [24]. Additionally, students carried a Likert scale survey to give their opinion of the workshop.

In addition to measuring the development of creativity, after the experiment, participants responded an anonymous questionnaire (five points Likert scale), to know the students' estimations of aspects of creativity of the Stella 3D workshop.

The evaluation results were given to the students. An assessment of creativity provides a complete learning experience, as the assessment plays a significant role in motivating students towards creative learning [13]. The control group conducted the workshop, but only with traditional exercises of normalized views. They took the same pre-test and post-test as the treatment group at the same time.

The templates of this workshop are freely available on http://www.anfore3d.com/anfore-stella-3d, an open access educative resource developed for engineering students by the DEHAES Research Group in the development of spatial skills at the University of La Laguna (http://dehaes.webs.ull.es). It is composed of several multi-platform, multi-support and multi-format resources intended for the teaching of analyses of forms and their representations.

4. Data Analysis and Results

As shown in Figure 4, the results of the ANOVA revealed a major effect of the test type, such that the post-test performance was higher than pre-test performance, F (1,70) = 18.02, $p < 0.001$.

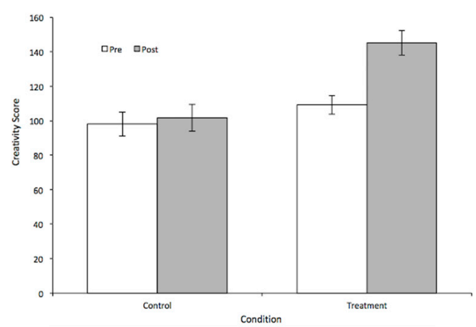

Figure 4. Pre and post-creativity score as a function of condition. Error bars represent standard error of the mean.

There was also a main effect from the condition category, indicating that the treatment group obtained better scores than the control group, F (1,70) = 9.72, $p < 0.01$. These main effects were qualified by a significant interaction, F (1,70) = 12.29, $p < 0.001$, which demonstrated no pre-to-post-test gain for students in the control group, $t < 1$, but a significant pre-to-post-test gain for students in the treatment group, t (44) = 5.72, $p < 0.001$.

Figure 5 represents the increase in each of the components obtained by the treatment group.

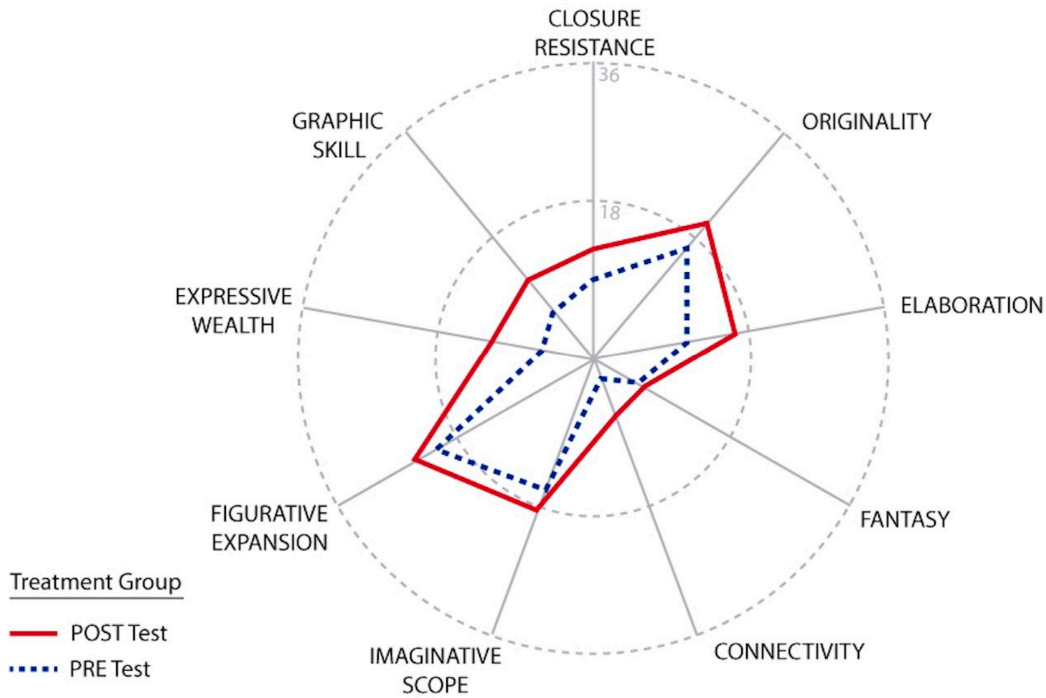

Figure 5. Graphical representation of the increase by component.

The results for the Likert scale questionnaire, conducted to discover the opinion of the participants on their assessment in the workshop and on their creativity, are in Table 1.

Table 1. Questionnaire.

Question (1–5 Likert Scale: 1 Strongly Disagree. 5 Strongly Agree)	Results
I consider myself a creative person	3.4
As a future engineer I consider it is important for my profession to develop my creativity competence	4.4
I believe that creativity can be developed through exercises	3.8
I think the Stella 3D workshop is a valid tool to develop my creativity	3.6
I think that in engineering it is necessary to consider several solutions to the same problem	3.7
I think that creative people are needed in today's sustainable engineering	4.0

5. Discussion and Conclusions

In order to contextualize the outcomes, recent research carried out by Saorin et al. [24] has been taken into account. They concluded that incoming fine arts students, traditionally, have a greater predisposition to creative tasks, and that the fine arts students obtained better results for the creativity test score than the incoming engineering students. Indeed, the values obtained in the pre-test by the participants in this experiment (109.09) are lower than those obtained by students of fine arts (159.50). However, it is interesting to note that after conducting the Stella 3D workshop, the creativity results in the post-test of engineering students, were approximate (145.12 versus 159.50) to the results obtained by the new students in fine arts.

The same test has also been used in other research developed by Valencia University, in which students of industrial design participated [60] in a PBL (project-based learning) activities. The result was a score of 112.7, with an improvement of 27.3 points. These values are slightly lower than those observed in the experiment conducted in this paper. In La Laguna University, three studies were conducted. In the first one, an activity was carried out with 44 students in the first year of engineering [25], in which designing and editing mesh software was used, as were 3D printers. Participants scored 139.2 in the post-test, these results being similar to those obtained by students in the experiment described in this article. In the second study, an activity was carried out with 31 students [86] in which the students worked with a 3D tangible version of the Stella 3D workshop. Participants scored 132.0 in the creativity test score post-test. In the third study, an activity was carried out with 115 students [85] in which the students using low cost digital manufacturing technologies created a 3D model of a terrain representation. Participants scored 122.0 in the post-test. In these experiments, students who did not perform specific 3D training (that is, the control group considered in each of the three cases) did not improve in creativity.

The conclusions in the light of the results obtained herein are:

The treatment and control group had similar creativity values before participating in the experiment (*p*-level = 0.21). The Stella 3D workshop, which was designed to foster students' ability to find multiple solutions to the same geometrical problem, improved the creativity of the participants in the treatment group, with significant gains in abreaction, originality, figurative expansion, expressive richness and graphic skill (see Table 2).

Table 2. A 2 (test: pre, post) × 2 (conditions: control, treatment) repeated measurement analysis of variance (ANOVA) was conducted to assess the impact of activity condition on creativity.

Creativity Factors	Control		Treatment		*t*-Student
	Pre	Post	Pre	Post	
	M (*SD*)	*M* (SD)	M (SD)	M (SD)	
Abreaction	13.36 (5.21)	10.51 (5.42)	10.88 (4.60)	14.22 (5.76)	4.22 **
Originality	14.30 (5.23)	15.51 (7.07)	18.80 (6.36)	22.99 (7.46)	1.67 +
Elaboration	9.89 (7.45)	12.66 (7.05)	12.96 (7.00)	18.63 (9.09)	1.62 +
Fantasy	3.95 (4.11)	4.47 (7.22)	6.91 (8.50)	7.59 (6.42)	0.09
Connectivity	4.94 (8.12)	7.99 (11.45)	3.37 (8.13)	8.47 (9.77)	0.86
Imaginative scope	13.66 (5.914)	14.20 (7.56)	17.99 (6.33)	20.63 (7.61)	1.34
Figurative expansion	24.15 (6.89)	23.60 (7.52)	22.71 (7.73)	25.65 (7.70)	1.90 +
Expressive richness	7.10 (4.83)	6.26 (6.09)	7.09 (5.06)	13.02 (10.55)	3.57 **
Graphic skill	6.75 (6.09)	6.32 (8.46)	8.38 (7.13)	13.97 (6.34)	3.47 **

Note. * $p < 0.10$; ** $p < 0.01$.

These results are comparable to other experiments performed with other engineering students in which the same test was used [24,25,60,85,86]. The participants of the treatment group increased in the abreaction component by 3.34 points, which means that they felt less conditioned to follow predetermined paths. In relation to originality, the improvement obtained a high value (4.19). Originality is the component with the most weight for diagnosing creativity. Guildford [89] (p. 334) stated "originality is the epitome or compendium of creativity." They also increased their ability to take risks (figurative expansion: 2.94), although to a lesser extent than the other components, which enables them to become more versatile engineers. Their use of color and perspective also improved, which contributes to greater expressiveness (5.93). Finally, another component that showed an increase was the graphical skill (5.59). Frequently, in the exercise of the engineering profession, it is necessary to draw a sketch to express an idea, and it is important that the interlocutor perceives the confidence of the engineer who transmits a quick, sure and concise line. Additionally, this composition is very present in the processes of computer-aided design in engineering.

The results for the control group in the creativity test score confirm that those students who did not participate in the Stella 3D workshop, that is to say that those that made regular exercises of normalized views with only one correct solution, did not improve in creative competence or in any of the components.

On the other hand, in the survey carried out, the students considered that creativity could be developed with exercises and that it was a very important competency for the profession of engineering. The Stella 3D workshop was well regarded by students as a type of exercise that helped them to develop creativity. Moreover, they considered creativity to be necessary in today's sustainable engineering. The survey was anonymous and the correlation of the results of the creativity test with the results of the questionnaire was not taken into account. It could be interesting, in future work, to look for correlations between the responses of the questionnaire and scores for the creativity measurement.

Creativity is an important tool in the search for a more sustainable future [1–3], directly linked to innovation and creative problem solving, so the Stella 3D workshop is a good tool for education in sustainable development. In that regard, it would be interesting to carry out an activity with a specific engineering sustainability project, in which different solutions could be proposed. That way, the transfer to a more realistic creative-thinking task, focused on sustainability, could be verified.

As future work, we propose looking for new 3D modeling exercises that stimulate creativity and divergent thinking. Currently, two creative lines with 3D modeling, called Wong 3D and Munari 3D, are under development. Other future work should be to carry out a Stella 3D workshop with spatial skills and creativity measurement to check relationships between these two skills.

Author Contributions: conceptualization, Jose Luis Saorin; formal analysis, Damari Melian-Diaz; funding acquisition, Carlos Carbonell-Carrera; investigation, Damari Melian-Diaz; methodology, Jose Luis Saorin; resources, Jorge de la Torre-Cantero; software, Jorge de la Torre-Cantero; writing—original draft, Carlos Carbonell-Carrera.

Funding: Spanish Ministry of Education, Culture and Sport, within the framework of the State Program for the Promotion of Talent and its Employability in I+D+I: the State Mobility Subprogram of the State Plan for Scientific and Technical Research and Innovation 20: CAS18/00033.

Acknowledgments: The research carried out is within the framework of action of the Spanish Ministry of Education, Culture and Sport, within the framework of the State Program for the Promotion of Talent and its Employability in I+D+i, the State Mobility Subprogram of the State Plan for Scientific and Technical Research and Innovation 2013-2016.

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

References

1. Sandri, O.J. Exploring the role and value of creativity in education for sustainability. *Environ. Educ. Res.* **2013**, *19*, 765–778.
2. Day, B.A. A generation of creativity. *Appl. Enviromental Educ. Comun.* **2006**, *5*, 229–230.
3. Hopkins, C.; McKeown, R. *Guidelines and Recommendations for Reorienting Teacher Education to Address Sustainability*; United Nations Educational, Scientific, and Cultural Organization: Paris, France, 2005.
4. Sternberg, R.J.; Lubart, T.I. *Defying the Crowd: Cultivating Creativity in a Culture of Conformity*; Free Press: New York, NY, USA, 1995.
5. Sternberg, R.J. *Estilos de Pensamiento*; Paidos Iberica, Ediciones S. A. Barcelona, Spain, 1999.
6. Weisberg, R. *Creativity: Genius and Other Myths*; WH Freeman/Times Books/Henry Holt & Co. New York, NY, USA, 1986.
7. Charyton, C. Creativity (Scientific, Artistic, General) and Risk Tolerance among Engineering and Music Students. Ph.D. Thesis, Temple University, Philadelphia, PA, USA, 2005.
8. Charyton, C.; Snelbecker, G.E. General, Artistic and Scientific Creativity Attributes of Engineering and Music Students. *Creat. Res. J.* **2007**, *19*, 213–225, doi:10.1080/10400410701397271.
9. Jagacinski, R.J.; Merrill, J.A.; Charyton, C. CEDA: A research instrument for creative engineering design assessment. *Psychol. Aesthet. Creat. Arts* **2008**, *2*, 147–154, doi:10.1037/1931-3896.2.3.147.
10. Charyton, C.; Merrill, J.A. Assessing General Creativity and Creative Engineering Design in First Year Engineering Students. *J. Eng. Educ.* **2009**, *98*, 145–156, doi:10.1002/j.2168-9830.2009.tb01013.x.
11. Cropley, D.H.; Cropley, A.J. Engineering creativity: A systems concept of functional creativity. In *Creativity Across Domains: Faces of the Muse*; Lawrence Erlbaum Associates Publishers. Mahwah, New Jersey, NJ, USA; 2005; pp. 169–185, doi:10.1017/9781316274385.015.
12. Elliott, M. *The Well-Rounded IE: Breakthrough Thinking*; London, UK, 2001; pp. 22–25.
13. Daly, S.R.; Mosyjowski, E.A.; Seifert, C.M. Teaching Creativity in Engineering Courses. *J. Eng. Educ.* **2014**, *103*, 417–449, doi:10.1002/jee.20048.
14. Cropley, D.H. Promoting creativity and innovation in engineering education. *Psychol. Aesthet. Creat. Arts* **2015**, *9*, 161–171, doi:10.1037/aca0000008.

15. Kazerounian, K.; Foley, S. Barriers to Creativity in Engineering Education: A Study of Instructors and Students Perceptions. *J. Mech. Des.* **2007**, *129*, 761–768.
16. Zappe, S.; Mena, I.; Litzinger, T. Creativity is not a purple dragon. In *VentureWell, Proceedings of Open, the Annual Conference*; National Collegiate Inventors & Innovators Alliance. Washington, DC, USA, 2013; p. 1.
17. Zappe, S.; Reeves, P.; Mena, I.; Litzinger, T. A cross-sectional study of engineering students' creative self-concepts: An exploration of creative self-efficacy, personal identity, and expectations. In Proceedings of the ASEE Annual Conference, Seattle, WA, USA, 14 June 2015.
18. Cropley, D.H.; Cropley, A.J. Creativity and innovation in systems engineering. Ph.D. Thesis, Systems Engineering Society of Australia, Adelaide, Australia, 1999.
19. Dewulf, S.; Baillie, C. *CASE: Creativity in Art, Science and Engineering: How to Foster Creativity*; Great Britain Department for Education and Employment, London, UK, 1999.
20. Fila, N.D.; Purzer, S.; Mathis, P.D. I'm not the creative type: Barriers to student creativity within engineering innovation projects. In Proceedings of the 2014 ASEE Annual Conference, Indianapolis, IN, USA, 15–18 June 2014.
21. Stouffer, W.B.; Russell, J.S.; Oliva, M.G. Making the strange familiar: Creativity and the future of engineering education. In Proceedings of the 2004 American Society for Engineering Education Annual Conference & Exposition, Salt Lake City, UT, USA, 20–23 June 2004.
22. Carbajo, J.C. *La Creatividad en la Educación Infantil, Primaria y Secundaria*; Eos: Madrid, Spain, 2000.
23. Casas, J. *Aprende y Enseña Jugando*; Absalon: Madrid, Spain, 2012.
24. Saorín, J.L.; De La Torre, J.; Melián, D.; Meier, C.; Lifante, Y. Competencia creativa en estudios de Grado en Ingeniería. In Proceedings of the Artículo Presentado al Congreso al III Congreso Sobre Aprendizaje, Innovación y Competitividad, Madrid, Spain, 14–16 October 2015.
25. Saorín, J.L.; Melian-Diaz, D.; Bonnet, A.; Carrera, C.C.; Meier, C.; De La Torre-Cantero, J. Makerspace teaching-learning environment to enhance creative competence in engineering students. *Think. Ski. Creat.* **2017**, *23*, 188–198, doi:10.1016/j.tsc.2017.01.004.
26. Scott, G.; Leritz, L.E.; Mumford, M.D. The effectiveness of creativity training: A quantitative review. *Creat. Res. J.* **2004**, *16*, 361–388, doi:10.1080/10400410409534549.
27. Badran, I. Enhancing creativity and innovation in engineering education. *Eur. J. Eng. Educ.* **2007**, *32*, 573–585, doi:10.1080/03043790701433061.
28. Cropley, D.H.; Cropley, A.J. Fostering creativity in engineering undergraduates. *High Abil. Stud.* **2000**, *11*, 207–219, doi:10.1080/13598130020001223.
29. Shah, J.J.; Smith, S.M.; Vargas-Hernandez, N. Metrics for measuring ideation effectiveness. *Des. Stud.* **2003**, *24*, 111–134, doi:10.1016/S0142-694X(02)00034-0.
30. Cockton, G. FEATURE Designing worth-connecting preferred means to desired ends. *Interactions* **2008**, *15*, 54–57.
31. Goldschmidt, G.; Smolkov, M. Variances in the impact of visual stimuli on design problem solving performance. *Des. Stud.* **2006**, *27*, 549–569, doi:10.1016/j.destud.2006.01.002.
32. Simpson, T.; Barton, R.; Celento, D. Interdisciplinary by design. *Mech. Eng.* **2008**, *130*, 30.
33. Charyton, C.; Jagacinski, R.J.; Merrill, J.A.; Clifton, W.; DeDios, S. Assessing creativity specific to engineering with the revised creative engineering design assessment. *J. Eng. Educ.* **2011**, *100*, 778–799, doi:10.1002/j.2168-9830.2011.tb00036.x.
34. Shneiderman, B. Creativity support tools: Accelerating discovery and innovation. *Commun. ACM* **2007**, *50*, 20–32.
35. De la Torre-Cantero, J.; Saorín, J.L.; Melián, D.; Meier, C. STELLA 3D: Introducing Art and Creativity in Engineering Graphics Education. *IJEE* **2015**, *31*, 805–813.
36. Prahalad, C.K.; Ramaswamy, V. The new frontier of experience innovation. *MIT Sloan Manag. Rev.* **2003**, *44*, 12–18.
37. Maeda, J. STEM I Art 5 STEAM. *STEAM J.* **2003**, *1*, 34.
38. National Governors Association. *Building a Science, Technology, Engineering and Math Agenda*; National Governors Association Center for Best Practices: Washington, DC, USA, 2007.
39. Perry, W.; Broers, A.; El-Baz, F.; Harris, W.; Healy, B.; Hillis, W.D. *Grand Challenges for Engineering*; National Governors Association Center for Best Practices: Washington, DC, USA, 2008.

40. Fernandes, A.A.; da Silva Vieira, S.; Medeiros, A.P.; Natal Jorge, R.M. Structured methods of new product development and creativity management: A teaching experience. *Creat. Innov. Manag.* **2009**, *18*, 160–175, doi:10.1111/j.1467-8691.2009.00529.x.
41. Atwood, S.A.; Pretz, J.E. Creativity as a factor in persistence and academic achievement of engineering undergraduates. *J. Eng. Educ.* **2016**, *105*, 540–559, doi:10.1002/jee.20130.
42. National Academies of Engineering. *Changing the Conversation: Messages for Improving Public Understanding of Engineering*; National Academies Press: Washington, DC, USA, 2008.
43. Ishii, N.; Miwa, K. Supporting reflective practice in creativity education. In Proceedings of the 5th Conference on Creativity & Cognition, London, UK, 12–15 April 2005; pp. 150–157.
44. Felder, R.M. On creating creative engineers. *Eng. Educ.* **1987**, *77*, 222–227.
45. Felder, R.M.; Woods, D.R.; Stice, J.E.; Rugarcia, A. The future of engineering education II. Teaching methods that work. *Chem. Eng. Educ.* **2000**, *34*, 26–39.
46. Zampetakis, L.A.; Tsironis, L.; Moustakis, V. Creativity development in engineering education: The case of mind mapping. *J. Manag. Dev.* **2007**, *26*, 370–380, doi:10.1108/02621710710740110.
47. Liu, Z.; Schonwetter, D.J. Teaching creativity in engineering. *Int. J. Eng. Educ.* **2004**, *20*, 801–808.
48. Guilford, J.P. Creativity. *Am. Psychol.* **1950**, *14*, 469–479.
49. Guilford, J.P. Three faces of intellect. *Am. Psychol.* **1959**, *14*, 469.
50. Guilford, J.P. *The Nature of Human Intelligence*; McGraw-Hill: New York, NY, USA, 1967.
51. Romo, M. *Psicología de la Creatividad*; Universidad de Santiago de Compostela: Santiago, Chile, 1996.
52. Romo, M. *Treinta y Cinco Años del Pensamiento divergente: Teoría de la Creatividad de Guilford*; Pirámide: Madrid, Spain, 1987.
53. Chen, C.K.; Jiang, B.C.; Hsu, K.Y. An empirical study of industrial engineering and management curriculum reform in fostering students' creativity. *Eur. J. Eng. Educ.* **2005**, *30*, 191–202, doi:10.1080/03043790500087423.
54. Seng, T.O. Thinking skills, creativity, and problem-based learning. In *Temasek Polytechnic Singapore*; Temasek Polytechnic: Singapore, Singapore, 2000.
55. MacNamara, S.M.; Olsen, C.; Steinberg, L.; Clemence, S. Inspiring Innovation. In *American Society for Engineering Education*; American Society for Engineering Education: Washington, DC, USA, 2010.
56. Bell, N.E. *Council of Graduate Schools*; Research Report, Washington, DC, USA, 2008.
57. National Academy of Enginering. *The Engineer of 2020: Visions of Engineering in the New Century*; The National Academies Press: Washington, DC, USA, 2004.
58. National Academy of Engineering. *Educating the Engineer of 2020: Adapting Engineering Education to the New Century*; The National Academies Press: Washington, DC, USA, 2005.
59. Tuning Project, Competences. From Tuning. Educational Structures in Europe. Available online: http://www.unideusto.org/tuningeu/home.html (accessed on 24 February 2014).
60. Lifante Gil, Y. *Ingenieros Creativos*; Editorial Alfa Delta Digital: Valencia, Spain, 2011.
61. Blancos, Libros. Available online: http://www.aneca.es/Documentos-y-publicaciones/Otros-documentos-de-interes/Libros-Blancos (accessed on 23 February 2016).
62. Sochacka, N.W.; Guyotte, K.; Walther, J. Learning together: A collaborative autoethnographic exploration of STEAM (STEM+ the Arts) education. *J. Eng. Educ.* **2016**, *105*, 15–42, doi:10.1002/jee.20112.
63. Smith, C.; Watson, J. STEM and Education for Sustainability: Finding common ground for a thriveable future. In Proceedings of the Australian Association for Research in Education (AARE) Conference 2016: Transforming Education Research, Melbourne, Australia, 27 November–1 December 2016.
64. Dollinger, S.J. "Standardized minds" or individuality? Admissions tests and creativity revisited. *Psychol. Aesthet. Creat. Arts* **2011**, *5*, 329.
65. Niaz, M.; Núñez, G.S.; Pineda, I.R. Academic Performance of High School Students as a Function of Mental Capacity, Cognitive Style, Mobility-Fixity Dimension, and Creativity. *J. Creat. Behav.* **2000**, *34*, 18–29, doi:10.1002/j.2162-6057.2000.tb01200.x.
66. Blake, S.; McCarthy, C.; Krause, J.A. The paradoxical nature of academic measures and creativity. *Creat. Educ.* **2014**, *5*, 797, doi:10.4236/ce.2014.510092.
67. Furnham, A.; Zhang, J.; Chamorro-Premuzic, T. The relationship between psychometric and self-estimated intelligence, creativity, personality and academic achievement. *Imagin. Cogn. Personal.* **2005**, *25*, 119–145, doi:10.2190/530V-3M9U-7UQ8-FMBG.
68. Treffinger, D.J. Assessment and measurement in creativity and creative problem solving. In *The Educational Psychology of Creativity*; Hampton Press: Cresskill, NJ, USA, 2003; pp. 59–93.

69. Hocevar, D.; Bachelor, P. A taxonomy and critique of measurements used in the study of creativity. In *Handbook of Creativity*; Springer: Boston, MA, USA, 1989; pp. 53–75.
70. Hocevar, D.; Michael, W.B. The effects of scoring formulas on the discriminant validity of tests of divergent thinking. *Educ. Psychol. Meas.* **1979**, *39*, 917–921.
71. Runco, M.A.; Okuda, S.M.; Thurston, B.J. The psychometric properties of four systems for scoring divergent thinking tests. *J. Psychoeduc. Assess.* **1987**, *5*, 149–156.
72. Torrance, E.P.; Ball, O.E.; Safter, H.T. *Torrance Tests of Creative Thinking*; Scholastic Testing Service: Princeton, NJ, USA, 1966.
73. Beketayev, K.; Runco, M.A. Scoring divergent thinking tests by computer with a semantics-based algorithm. *Eur. J. Psychol.* **2016**, *12*, 210.
74. Acar, S.; Runco, M.A. Assessing associative distance among ideas elicited by tests of divergent thinking. *Creat. Res. J.* **2014**, *26*, 229–238.
75. Larson, M.C.; Thomas, B.; Leviness, P.O. Assessing creativity in engineers. *Des. Eng. Div. Successes Eng. Des. Educ. Des. Eng.* **1999**, *102*, 1–6.
76. Owens, W.A. *The Owens' Creativity Test for Machine Design*; Iowa State University Press: Ames, IA, USA, 1960.
77. Lawshe, C.H.; Harris, D.H. *Manual of instructions to accompany Purdue Creativity Test Forms G and H*; Educational Testing Services: Princeton, NJ, USA, 1960.
78. Guildford, J.P. Varieties of divergent production. *J. Creat. Behav.* **1984**, *18*, 1–10.
79. Oliveira, E.; Almeida, L.; Ferrándiz, C.; Ferrando, M.; Sainz, M.; Prieto, M.D. Tests de pensamiento creativo de Torrance (TTCT): Elementos para la validez de constructo en adolescentes portugueses. *Psicothema* **2009**, *21*, 562–564.
80. Corbalán, F.J.; Martínez, F.; Donolo, D.; Alonso, C.; Tejerina, M.; Limiñana, R.M. *CREA. Inteligencia Creativa. Una Medida Cognitiva de la Creatividad*; TEA Ediciones: Madrid, Spain, 2003.
81. De la Torre, S. *Evaluación de la Creatividad: TAEC, un Instrumento de Apoyo a la Reforma*; Escuela Española: Madrid, Spain, 1995.
82. Artola González, T.; Barraca Mairal, J. Creatividad e imaginación. Un nuevo instrumento de medida: La PIC. *EduPsykhé* **2004**, *3*, 73–93.
83. Garaigordobil Landazabal, M.; Pérez Fernández, J.I. Efectos de la participación en el programa de arte Ikertze sobre la creatividad verbal y gráfica. *Anales Psicol.* **2002**, *18*, 95–110.
84. Garaigordobil, M.; Pérez, J.I. Un estudio de las relaciones entre distintos ámbitos creativos. *Educ. Cienc.* **2004**, *16*, 11–21.
85. Carbonell-Carrera, C.; Saorin, J.L.; Melian, D.; de la Torre Cantero, J. 3D Creative Teaching-Learning Strategy in Surveying Engineering Education. *Eur. J. Math. Sci. Technol. Educ.* **2017**, *13*, 7489–7502, doi:10.12973/ejmste/78757.
86. Melian, D.; Luis Saorin, J.; de la Torre-Cantero, J.; Diaz, D. Tangible 3D Printed Workshop for introducing Art and Creativity in Engineering Drawing Subject. *IxD&A* **2017**, *34*, 30–42.
87. Guilford, J.P. *Guilford Test for Creativity*; Sheridan Supply Company: California, CA, USA, 1951.
88. Torrance, E.P. *Torrance Tests of Creative Thinking (TTCT)*; Norms Technical Manual; Personal Press Inc.: Princeton, NJ, USA, 1966.
89. Guilford, J.P.; Hoepfner, R. *The Analysis of Intelligence*; McGraw-Hill Companies: New York, NY, USA 1971.