This is a previous version of the article published in Behaviour & Information Technology. 2016, 35(11): 897-906. doi:10.1080/0144929X.2016.1215525

Using Virtual Reality for industrial design learning: a methodological proposal

Abstract. Nowadays, the different computer tools available enable designers to create complex industrial prototypes. The use of these tools is constrained by the limitations imposed by common devices, like screens and displays. Recently emerged Virtual and Augmented Reality techniques have started being used as supports in many learning and industrial environments. Beyond the new possibilities that these tools offer for designing industrial objects, the underlying question is whether these new technologies could improve the creativity of designers to enable them to get a better understanding of the designing process itself. This paper presents a methodological proposal for the deployment of an industrial design engineering course aimed not only at learning different design techniques, but also at assessing the creativity skills of students. The practical contents include the use of VR devices, to help the designer overcome the limitations of prototype visualization and make better designing decisions. Moreover, a creativity test will be performed at the beginning and at the end of the course to assess the changes in creativity skills, taking place within the experiment group versus the changes in a traditional learning (control) group.

Keywords virtual reality, learning, industrial design, creativity.

1. Introduction

Virtual Reality (VR) and Augmented Reality (AR) have raised an enormous breakthrough in the way designers can interact with synthetic objects. In fact, the constraints of 2D visualization are breached giving way to a rich immersive 3D experience, even with the incorporation of haptic interfaces so as to enhance the user sensations.

The application of these technologies is quickly increasing to support a wide range of disciplines, not only at academic and teaching levels, but also in real engineering and industrial processes.

At this point, one of the major questions which arises deals with the way AR/VR improves the learning process. There is no doubt that the feature of immersion creates a much more motivating environment for students, as they become active participants in this process. With regard to industrial design, an essential ability that needs to be enhanced is creativity. Indeed, in an increasingly competitive environment, companies feel compelled to invest in continuous innovation. Product innovation is the key in this process. Therefore, research on methods and technologies which support creative thinking must be a priority for every competitive enterprise (Li et al., 2007). Training in cognitive skills is of fundamental importance in the development of creativity.

The evaluation of creativity strengthening is difficult to implement, mainly because in the process of creative design several subjective factors are involved. In fact, Torrance (1998) considers creative design as a process which includes adventurous thinking, inventiveness, discovering, curiosity, and imagination. Among the few methods intended to measure creativity, it is worthwhile mentioning the Torrance Test of Creative Thinking - TTCT (Torrance, 1974) and the Creative Imagination Test - PIC (Barraca et al., 2010).

In the next subsections we will address a series of works about AR/VR environments applied to learning and industrial design. Moreover, a review about the assessment of skills improvement when using these technologies will be shown. The shortcomings found in these works will be used as the basis for the proposal of an industrial design course supported by AR/VR. The course formulation includes an evaluation of improvements in creative thinking achieved with the use of these technologies.

1.1. Virtual/Augmented Reality Learning Environments

Virtual reality (VR) and augmented reality (AR) technologies have, for a long time, been used as supports in teaching-learning processes in various educational fields. Proposals have been developed to improve the results of teaching in primary and secondary education (Isik-Ercan et al., 2012) and children with special needs (Strickland, 1997, Bellani et al., 2011). At the post-secondary level, most works on the topic have focused on the simulation of surgical processes and other medical therapies (Aggarwal et al., 2006, Lemole et al., 2007).

With regard to AR/VR oriented to engineering and industrial design, several works can be found (Impelluso and Metoye, 2000, M. Nomura, Y. Sawada, 2001, Stone, 2001, Ong and Mannan, 2003, Zwolinski et al., 2007, Shen et al., 2009, Bruno and Muzzupappa, 2010, Hashemipour et al., 2011, Jimeno-Morenilla et al. 2013). The purpose of these studies is to promote the use of virtual reality tools and to help understand complex concepts through interdisciplinary, collaborative work environments and conditions that, for various reasons, are not easy to recreate in a non-virtual world.

One example of a well-referenced VR platform is the *Computer Automatic Virtual Environment* (CAVE), designed by the *Laboratory of Electronic Vision* in Chicago (Cruz-Neira et al., 1993). Multiple users can interact with each other within the shared virtual environment. This system has different variants, each of them issued for a specific application, such as virtual meetings using the TCP/IP protocols, simulation of virtual tours (museums, research laboratories, and centres of business production), and so on. A CAVE application is, therefore, a virtual reality environment that allows experiences with a high degree of immersion. These environments are mainly applied in the realization of experiments, skills training, academics, and business. It avoids economic and even human costs in various areas such as defense, medicine, computer sciences, and more. However, the technology is expensive and trained staff is required for its installation and maintenance.

The system COSTAR *(Cable Organisation System Through Alternative Reality*), developed at Heriot-Watt University in Edinburgh, allows the engineer to design electrical systems in a virtual environment (Ritchie et al., 2006). The designer can enter the path which circulates the cable simply by selecting points in 3D spaces. The system is limited by its specific field of use, since it does not allow its application in other areas.

1.2. Enhancing Abilities through Virtual/Augmented Reality

One of the recurring issues in works on learning supported by virtual reality is the way in which this technology strengthens the diverse abilities of students, including creativity (Abulrub et al., 2011). Despite its importance in autonomous learning and capabilities of future engineers and designers, the strengthening of such quality by virtual learning environments has not been sufficiently proven. In fact, most projects focus on assessing the quality of immersion and interaction within the environment, as well as its level of comfort. (Saleeb and Dafoulas, 2011). Aspects such as the development of imagination and creativity are most of the time secondary issues, mainly due to the fact that they are particularly difficult to measure objectively (Thorsteinsson and Page, 2007).

Kim (2006), investigated the ideas proposed by Torrance to evaluate creativity. The fundamental conclusion of the work is that the TTCT provides a basis on which to establish the idea that creativity can be scaled and increased through practice, and that this test may even be used to discover and promote the creative abilities of the population in general.

Lehtonen (2005), emphasizes the need to enhance the aesthetic and emotional learning process aspects so that they acquire the same significance as the cognitive and rational aspects. These aspects could be greatly enhanced with these new AR/VR technologies. The work concludes that new generations of students adopt an active attitude in their process of learning rather than remain mere observers. This enhances even further the usefulness of AR/VR technologies in learning processes.

Bell and Fogler (1995) published a series of recommendations made by Felder and Silverman (1988) added to the Bloom's taxonomy (1956) to enhance the educational methods for students depending on instructors teaching styles and students learning abilities, which often do not match. The emphasis was placed on the advantage of applying Virtual Reality in higher education to suit the styles previously outlined. They designed a course for chemical engineering supported by the Virtual Reality environment Vicher (*Virtual Chemical Reaction Module*). The course aims to serve as a guide in teaching chemical reactions to different students with different learning capabilities, as well as assess the quality and effectiveness of these technologies in the teaching-learning process. In this evaluation, students were subjected to an examination composed of a series of questions about engineering before and after using the simulator. The students were given the chance to change their answers after their virtual experience and evaluate it. As a result, the answers after using the VR environment were generally more precise and showed a better understanding of engineering concepts. The vast majority also said that the VR environment had enhanced their learning experience.

Häfner (2013), presented the design of a course to learn how to create virtual worlds in an interdisciplinary way, industrial projects between people studying different degrees and promoting the development of various skills. The course evaluation is obtained through a series of questionnaires especially formulated for the students, as well as the project portfolio. The results showed that the quality of learning was much higher.

Hashemipour (2011), proposed the use of a virtual reality environment for mechanical and industrial engineering. The system consists of five modules, each of them oriented to support the learning of a component of industrial development. The assessment of students is carried out in two phases: the first involves the use of the virtual environment to perform certain tasks. Second, they perform the same tasks in an environment with real hardware. Students are provided a test for checking their understanding of the experiment, as well as a series of questions about their virtual experience. The usability of the system is evaluated by means of a questionnaire based on the method of evaluation SUMI (learning ability, efficiency, utility, control, effectiveness) (Kirakowski, 1994). These sub-categories are joined by five categories of virtual reality: clear entry and exit points, sense of presence, navigation and orientation, faithful viewpoints, and realistic feedback.

Miyata (2010) suggested the formation of interdisciplinary groups to promote creativity when it comes to developing VR applications. Thinking outside the box is encouraged and essential. The evaluation of the teaching and learning process is carried out through a questionnaire of 13 dimensions, which assesses the collaborative process on the one hand, as well as another questionnaire of five dimensions geared towards evaluating the individual process in five aspects.

Sutcliffe and Gault (2004) proposed a set of criteria for evaluating the usability of a VR application. Twelve aspects, which must be scored by the users of the environment, are mainly oriented to test the user interface in each of its different aspects.

Jou and Wang (2013) focused on the influence of Virtual Reality learning environments on technical skills such as knowledge, comprehension, simulation, application, and creativity. In the study, one of the variables that is intended to be measured is the utility of such environments regarding the training of the technical skills to students. Two groups are created: a control group with a traditional educational system and the other using virtual reality tools. The answers to the multiple choice test are then evaluated, as well as a series of questions regarding four thematic blocks of engineering. This is one of the few projects that focused on statistical results, although students were asked very specific question and no standard criteria was followed. Moreover, these were not designed to evaluate the improvement of the individual's creativity when using the new learning system.

To summarize, most works on AR/VR applied to industrial design learning focuses on technology, from the point of view of its functionality, usability and aesthetic factor. However, the impact it causes on the improvement of users skills is not rigorously evaluated or, when done, the assessment does not follow a standard method that can be generalized.

The objective of the project presented in this article is to develop a proposal for a course in industrial 3D design and the application of virtual reality techniques. This proposal also adds an evaluation of the methodology, which seeks to quantify the impact these techniques may have on academic students and their creative ability.

This article is structured as follows: section 2 details the course proposal, including the theoretical and practical contents, planning and student assessment. Section 3 presents an evaluation of the methodological proposal , and in section 4, conclusions are exposed.

2. Proposal development

2.1 Course Content

Industrial Engineering is a degree that includes an aim to train professionals capable of developing products or prototypes for various industries, such as automotive, furniture design, fashion, toys, etc. An Industrial design course composed of 220 hours is proposed to complete the product design training. Other degrees such as Architecture and Civil Engineering can also benefit from this course as they share concept similarities and design objectives.

2.2 Experimental Methodology

The course will be comprised of two groups with 20 students in each group. In the experimental group, VR techniques will be used as a product design support tool. In the second group, (the control group), traditional teaching methods will be used. That is, in this group, the VR sessions are replaced by 3D design software. The objective of this group, which does not use VR techniques, is to evaluate the validity of the proposal.

Both groups are assessed initially with an initial test (pre-test) and another one (post-test) upon completion. The results achieved are analyzed and compared using statistical techniques. The tools and the statistical methods used to validate the proposal will be presented in section 3 of this article.

2.3. Industrial Design Course

The course aims to teach students in the design and implementation of models and/or prototypes using a 3D design tool. The course addresses the basic design of an object, using 3D modelling, applying materials, textures and lighting effects to give it a realistic finish. The experimental group will also use virtual reality glasses to support the display of the prototype and provide the student a sense of immersion.

2.3.1 Material software and hardware.

The software tool used is 3D Studio Max ®. This software is commonly used in professional and educational environments and offers a wide range of options to facilitate the design of elements. There is also a wide variety of plug-ins and software available online that offer enhanced possibilities, including viewers prepared for the creation of virtual worlds. Such is the case with Sketchfab ® for 3DS, a free system that allows the designer to export models created with 3DS to create a sense of immersion with the appropriate hardware.

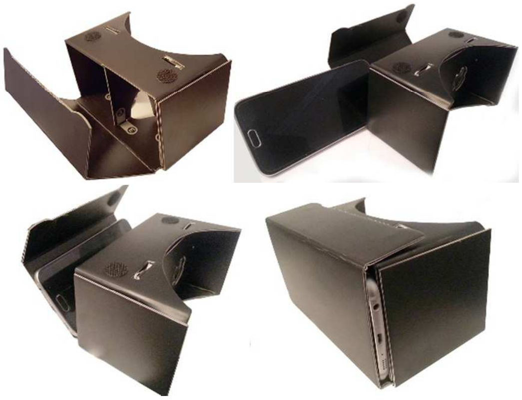

Figure 1. Google Cardboard® kit.

Regarding the display device, there exists in the market a wide range of VR/AR devices capable of providing immersive sensations of varying quality. The cost of these devices as well as their benefits can vary significantly. This course is an experimental proposal, and for this reason, an expensive device is not required. Therefore, we have opted for Google Cardboard ® glasses. These low-cost glasses (<$ 5) allow the designer to create the sense of immersion, using a Smartphone with a medium or high-resolution screen. (See Figure 1).

2.3.2 Learning Methodology

The course is divided into theoretical and practical sessions, with an emphasis on practical orientation. Hence the theoretical content is approximately 30% (70 hours) and the practical is 70% (150 hours).

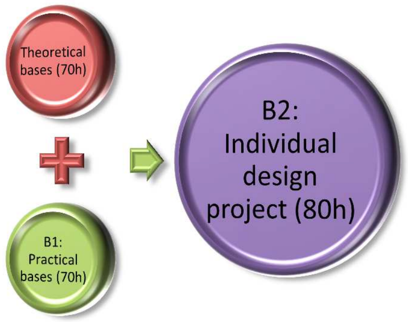

Figure 2. Block scheme of the industrial design course.

Table 1. Theoretical Content

ID	*Description*	*h*
T1	General concepts of Industrial Design.	8
T2	Introduction to the Product Creation process.	8
T3	Hardware introduction.	2
T4	Operating Systems introduction.	2
T5	Computer Language.	2
T6	Introduction to drawing software, presentation and retouching.	2
T7	File Management.	4
T8	3D Geometrics: CSG and NURBs.	8
T9	3D Editing.	8
T10	Model Rendering.	6
T11	Creating light sources.	6
T12	Creating and applying Textures.	6
T13	Product Presentation.	8

The course methodology is oriented to active learning. It is based on student participation, investigation, and autonomous learning. To do so, it will start from the ideas and preconceptions of students on the conception of new designs, favouring student involvement in the teaching and learning process. Content and activities will be more significant for students and directly related to the professional world of industrial design and considering the design of realistic models. In addition, the functionality, such as use of media, techniques and teaching resources, aim to better understand 3D design, its applications and consequences.

For the project development, each student will create his own original design. Previously teachers will explain the theoretical fundamentals to develop projects. In the practical implementation, the teacher should act as a catalyst for knowledge and provide the necessary assistance for individual problem resolution during the creative process.

2.3.3 Learning Strategy

One of the most important aspects when it comes to organizing the sessions is that there must be a balance between the theoretical and practical sessions, where the student is taught theoretical knowledge and its application.

Table 2. Practical content.

	ID	*Description*	*H*
B1: acquisition of skills	B1.1*	Installing and configuring of SW/HW.	4
	B1.2*	2D/3D Image presentation and editing.	4
	B1.3	Drawing file management: importing and exporting.	4
	B1.4*	Using Scanner for designing objects.	4
	B1.5	Drawing geometric shapes: dots, lines, ovals, arcs, spline, axis and polygons.	4
	B1.6	Managing coordinates and annotation.	4
	B1.7	Modifying geometric shapes in 3D: join, difference, intersections, sections, plan de cut y modification.	10
	B1.8	3D realism: use of light, colour and texture, roughness, brightness and reflection.	12
	B1.9	Construction of virtual environments to locate objects.	12
	B1.10	Guided tour of a simple model creation.	12
B2: full design project	B2.1	Presentation of the individual project: Practical guide.	4
	B2.2	Model conception.	8
	B2.3	Establishment of requirements and specifications of the product.	10
	B2.4*	Prototyping.	12
	B2.5*	Functional analysis and redesign.	12
	B2.6*	Artistic analysis and redesign.	12
	B2.7*	Creation of virtual environment.	12
	B2.8*	Product presentation and validation.	10

* indicates that the practice involves VR use for the experimental group.

The theoretical content displayed in Table 1, provides the knowledge base needed for students to successfully address the fundamental aspects of projects. This content consists of 70 hours, only taught during the first half of the course. Please note that the theoretical content for the two groups mentioned earlier in this proposal is identical. The experimental group will use VR techniques whilst the control group will not use these techniques.

The practical contents are divided into two blocks (see Table 2): the B1 and B2 blocks. Block B1 is geared towards acquiring the skills required to manage the 3D design software. This 70-hour block with 10 practical sessions coincides in time along with the delivery of the theoretical contents, as shown in Figure 2.

The B2 block's aim is to get students to create a full design project. This 80-hour block will be held in the second half of the course, after the theoretical content and block B1 practices have been taught.

2.3.4 VR Sessions

In the experimental group, VR techniques will be used to complement design learning. These techniques will be applied mainly during the development of individual projects (planned for the B2 block). Previously, in the B1 block, specifically in practices B1.1, B1.2, and B1.4, students are trained in the installation and basic use of elements that will be used to create the feeling of immersion in the virtual world: the Sketchfab® for 3DS software and device Google Cardboard ® linked to a Smartphone.

Figure 3. 3D sketch of design

Students in the experimental group will benefit from the use of virtual reality to improve the object design perception in B2 block: from its initial conception (B2.4) until its final presentation (B2.8). However, students are expected to use it intensively in practices B2.5 and B2.6 where it is expected that the feeling of immersion will improve the perception of the functionality (B2.5) and the artistic value of the model (B2.6), to guide students into making new decisions and introducing design changes that will give added value to the product.

In particular, in session B2.4, students will be expected to make an initial approach to the product design, using 3D design tool (see Figure 3). In this sketch, an immersive viewing could be already performed as shown in Figure 4.

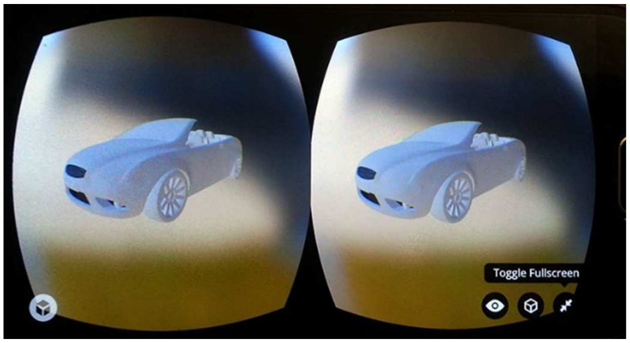

Figure 4. Image generated with Sketchfab ® for viewing on a smartphone and VR glasses.

As already mentioned above, practices B2.5 and B2.6 are oriented to the redesign of the product, improving its functional and aesthetic aspects. Here the professor will offer his or her experience so students will rethink and upgrade their options using VR techniques (in the case of the experimental group), or solely by using 3D design software (in the case of the control group). The purpose of these sessions is to create a full prototype (see Figure 5).

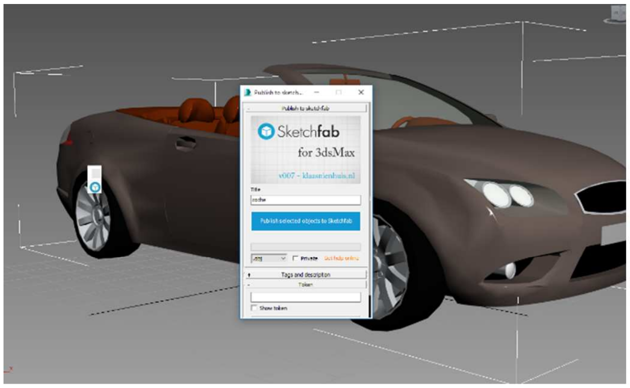

Figure 5. Image of the product design prior to its integration within the environment

Practice B2.7 addresses product presentation. The goal is to be able to place and integrate the object in the environment for which it was designed. Again, students in the experimental group will have the opportunity to use VR glasses to have an immersive feeling and, where appropriate, improve aesthetic aspects that provide a greater integration of the product with its context.

Finally, practice B2.8 is designed so students can present their ideas to both teacher and peers. Each student will have aproximately 30 minutes to present his projects and ideas, after which design, development and future implementation issues will be discussed.

2.3.5 Student assessment

The evaluation will be initial, procedural and final. The initial evaluation consists of a theoretical test that allows the teachers to determine the level of knowledge students have in 3D design, prior to the course. The result of this initial test will not be considered for the final grade of the course. Procedural assessment in its formative function consists of the assessment, through the continuous and systematic collection of data, of work carried out by the students, on all previously set theoretical and practical contents. The final evaluation aims to assess the results obtained by the students at the end of the teaching and learning process.

The procedural or continuous assessment will be carried out by the teacher who was present during the entire process; taking into consideration the students' work and development of practical content. Specifically, this assessment will be carried out attending the concept of *mix design*, a term coined by Philip Kotler (2010), which includes the aspects of functionality (PFT), quality (PQT), cost (PCT), durability (PDT) and aesthetics (PAT) as major components of the design process of a product (see table 3). These aspects will be taken into account by the teacher and will count towards 50% of the student's final grade.

Table 3. Criteria of evaluation of students

Type	*Rule*	*% (ID)*	
Theorical (25%)	Specific knowledge on 3D design	25 (FT)	
Project assessment (75%)	Items	by teacher (continuous)	by peers (final)
	Functionality	10 (PFT)	5 (PFP)
	Quality	10 (PQT)	5 (PQP)
	Cost	10 (PCT)	5 (PCP)
	Durability	10 (PDT)	5 (PDP)
	Aesthetics	10 (PAT)	5 (PAP)

On the other hand, two types of final evaluations will take place. One of the evaluations is aimed at assessing the theoretical knowledge acquired by students, through a test of 40 multiple choice questions (called FT at table 3). This test will count towards 25% of the student's final grade. The second and final evaluation will be the result of the presentation of the individual project. This presentation will be judged by the student peers, assessing individually each one of the 5 criteria commented above. In this case, the aspects of functionality (PFP), quality (PQP), cost (PCP), durability (PDP) and aesthetics (PAP) shown in table 3, result the 25% of the student's final grade.

The expression (1) summarizes the three components used to calculate the students´ final grade, that is, the final theoretical test (25%), the project assessment carrid out by the teacher during the course (50%), and the peers' evaluation of the final presentation of the individual project at the end of the course (25%).

$$\begin{aligned}\text{Final Grade} \quad = \quad & 0.25\ \text{FT} \\ & + 0.50\ (\text{PFT} + \text{PQT} + \text{PCT} + \text{PAT} + \text{PDT}) \\ & + 0.25\ (\text{PFP} + \text{PQP} + \text{PCP} + \text{PAP} + \text{PDP})\end{aligned} \tag{1}$$

3. Evaluation of the proposal

Given the innovative nature of this proposed methodology, assessment mechanisms that detect defects and improve future editions will be established. In order to mitigate potential biases in results, the creation of two groups is proposed: the experimental group, where the VR experience will be held, and the control group, which will follow a methodology based exclusively on 3D design software. Students will be assigned randomly to the two different types of groups; each group will be composed of 20 individuals.

Once the course is evaluated, and if the experience proves to be successful, the control group will be removed so all students will be able to benefit from using virtual reality techniques applied to industrial design.

Three evaluations and a contingency plan are proposed. Two of these evaluations are intended to establish, as objectively as possible, the comparison between the levels of academic achievement and creative thinking of both the control and experimental groups. A third evaluation shall include, as a survey, the opinion of participants in the educational experience, so to draw conclusions about the suitability of the course or improvements that need to be introduced.

Simultaneously, a contingency plan shall be established to reduce the risks that face the proposal, the likelihood that they occur and how to act in each case. Each of these elements is discussed in detail below.

3.1 Evaluation of creative thinking

The Torrance Test of Creative Thinking (1974) is the test most widely used to evaluate divergent thinking, and still widely used worldwide today. Students give multiple responses to stimuli such as verbal and shapes, scored according to fluidity (or the number of ideas); flexibility, with regard to the variety of perspectives represented in the ideas; originality (the statistical rarity) and the elaboration of ideas more required by the stimulus.

The objective of the test is to assess creativity. The instrument allows, on the one hand, to operationally determine various kinds of attitudes, psychological functioning and psychological characteristics that facilitate or inhibit the creative process. On the other hand, it helps understand different types of productions resulting from creative processes, as well as the personality of the individuals involved in creativity, success and all the conditions that favour it.

Regarding this proposal, the hypothesis being tested is to determine whether there is a significant difference in the creativity thinking level, of students using VR devices (experimental group) and the students that did not use any VR technology (control group), after course completion.

The design used to test the hypothesis is, specifically, a "non-equivalent control group design" (Campbell and Stanley, 1966) with pre-test and post-test control groups. Torrance test will be applied twice to each group. An initial test (or pre-test) and a final test (or post-test). Once administered the tests, a comparative statistical study on the results of the pre-test and post- tests that the students of the two groups (control and experimental) performed at the beginning and at the end of the course will take place. In this design the independent factor will be the membership of one or another group, and the criterion or dependent variables will be the scores achieved in the test of creative thinking.

The effect of the methodology will be analyzed by means of the variance univariate Split-plot within the General linear model procedure. Additionally, interaction graphs will be created to represent the differences observed for the experimental and control groups in the pre and post-test situations and to observe the direction of the differences. Finally, a comparison of averages will be conducted to determine whether there were significant differences in the scores of the experimental and control groups.

3.2 Evaluation of academic achievement

This type of assessment aims to examine possible differences between the learning of the theoretical concepts that are exercised throughout the course. In order to do so, it is intended to analyze the marks of the two theoretical tests carried out throughout the course. First, we will analyze the result of the initial test of knowledge (see section 2.3.5), performed at the very beginning of the course to determine the starting knowledge level of the students. The goal is to confirm the hypothesis that there is no significant difference in knowledge skills between the control group and the experimental group at the beginning of the course. The statistical procedure will use the score of the initial knowledge test as the dependent variable and as the independent variable the membership of one or another group.

Once verified that both groups have the same starting situation, the results of the theoretical final test (FT at table 3) of both groups will be analyzed. To do this, a comparison of means will be carried out to determine whether there are significant differences in the performance of the experimental group and that of the control group, using the score of the FT test as the dependent variable and the membership of one or another group as the independent factor. As explained at the beginning of this section, the final theoretical test consists of 40 items with 4 possible answer options. This score is calculated using the expression (2) where failures are taken into account in order to avoid the effect of random responses. FT is in the range [0,100].

$$\mathrm{FT} = \left(\mathrm{CA} - \frac{\mathrm{WA}}{3}\right) \times 2.5 \qquad (2)$$

where CA is the number of correct answers and WA is the number of wrong answers.

The statistical procedure used for the mean comparison of both the scores of the initial test and the final theoretical test, will be the t-student test. All the statistical analyses will be performed using the SPSS program (version 21.0).

3.3 Satisfaction surveys

The satisfaction survey will be held anonymously to the participants in the experimental group. It consists of 20 questions with different mode of response: Likert scale (1-5), YES/NO and open (see Appendix A).

Questions with five response choices have as options "1: no agreement, 2: somewhat agree, 3: quite agree, 4: agreement and 5: totally agree". These questions aim to determine the degree of satisfaction and involvement of students in the experimental proposal, as well as to qualify their experience with VR devices.

On the other hand, questions with YES/NO options try to seek concrete answers about the suitability of the proposal or possible errors in the methodology. Open response questions are designed to clarify the reasons that led students to answer such questions.

3.4 Contingency plan

The objective of this plan is to have planned the actions that need to be taken if course expectations are not met, i.e., the use of VR techniques does not affect both performance and creative thinking positively.

Contingencies are classified according to the likelihood of their occurrence (high/medium/low) and its impact (high/medium/low). For each situation, a plan of prevention is proposed (preventative measures to avoid it), an emergency plan (measures to analyze the damage once it occurs) and a recovery plan (measures to control the situation and recover).

After advice from experts in the subject of 3D Industrial Design, a high-risk threat, a medium-risk threat, and three low-risk threats were identified (see Table 4). Almost all of them foresee a medium impact in the course that would require the acquisition of more sophisticated VR systems to increase the immersion sensation and the ability of interacting with the models.

The threat of greater impact in the course would the one that cause VR techniques to worsen the knowledge acquisition of students. This threat has a low probability in the current VR system given the simplicity of their management. For this reason, experts think that it would be hardly prejudicial the time that students spend acquiring knowledge.

Table 4. Contingency plan for the proposal

Threat	Prevention	Emergency	Recovery	Prob.	Imp.
There is no significant increase in performance	The use of VR will motivate students leading to an increase of interest in the course	The results of the satisfaction survey are analyzed	New VR devices are proposed or the number of hours dedicated to VR are reduced	Medium	Medium
There is no significant increase in creative thinking	The VR provides new evidence and enrich the creative experience	The results of the satisfaction survey are analyzed	New VR devices are proposed so as to increase the immersion sensation according to cost	High	Medium
There is a significant decrease in performance	The use of VR is simple in the context and does not imply waste of time for studying	The results of the satisfaction survey are analyzed	It proposes a reduction in the number of hours dedicated to VR devices or the use of more user-friendly VR systems	Low	High
There is a significant decrease of the creative thinking	The use of VR does not restrict creative options	The results of the satisfaction survey are analyzed	It proposes new VR devices that increase the immersion sensation.	Low	Medium
The satisfaction surveys do not give good results	The use of VR will be innovative and motivating for students	The results of the satisfaction survey are analyzed	It proposes a change of methodology that is consistent with the expectations of students	Low	Medium

4. Conclusions

The use of AR/VR devices is on the rise and devices are increasingly realistic and less expensive. Usage growth of these devices has resulted in a greater number of applications being made available for educational purposes.

The state-of-the-art analysis shows that most VR/AR educational proposals have been widely accepted among students. However, this is often related to the motivation that leads to the use of the technology rather than an effective increase in learning. As commented in the introduction section, there are few cases where the impact on students is studied through statistical procedures that analyze satisfaction surveys. Therefore, there is no evidence of studies that analyze the impact of VR based courses on creativity using more objective instruments which are broadly accepted by the international scientific community.

This paper has presented a methodological proposal that addresses the use of VR technologies among students where it is expected that these technologies will have a significant impact on industrial design. The proposal includes the detailed elaboration of theoretical and practical contents as well as a time planning and a systematic evaluation of students.

One of the main contributions of this research is the presentation of a proposal to assess the methodology itself. This assessment focuses on statistical tests intended to measure objectively the impact that the use of VR/AR technology may have on creative thinking as well as students' academic performance. It also raises a contingency plan that faces possible unwanted effects, based on the results of the assessment and the analysis of a satisfaction survey, suggesting improvement measures may have to be introduced.

Although the proposal focuses exclusively on 3D industrial design, its generic approach to evaluation and improvement could be easily extrapolated to other disciplines.

This methodology is expected to be implemented during 2016- 2017. It is then when the proposal is put to the test and the first conclusions regarding impact of VR technologies on industrial design in 3D learning will be able to be obtained.

5. References

Abulrub, A.G., Attridge, A.N., & Williams, M.A. (2011) Virtual reality in engineering education. The Future of Creative Learning, In Proceedings of the Global Engineering Education Conference (EDUCON 2011), Amman, Jordan.

Aggarwal, R., Grantcharov, T.P., Eriksen, J.R., Blirup, D., Kristiansen, V.B., Funch-Jensen, P., & Darzi, A. (2006) An evidence-based virtual reality training program for novice laparoscopic surgeons, *Annals of surgery*, 244(2), 310-314.

Barraca, J., Poveda, B., Artola, T., Mosteiro, P., Sánchez, N., & Ancillo, I. (2010). Three versions of a new test for assessing creativity in Spanish population (PIC-N, PIC-J, PIC-A). ECHA 2010 Paris Conference.

Bell, J.T., & Fogler, H.S. (1995). The investigation and application of virtual reality as an educational tool. In Proceedings of the American Society for Engineering Education Annual Conference, Annaheim, USA.

Bellani, M., Fornasari, L., Chittaro. L., & Brambilla, P. (2011) Virtual reality in autism: state of the art. Epidemiology and Psychiatric Sciences, 20(3), 235-238.

Bloom, B.S. (1956) *Taxonomy of Educational objectives: The Classification of Educational Goals, Handbook I: Cognitive Domain*. David McKay Company, New York.

Bruno, F., & Muzzupappa, M. (2010) Product interface design: A participatory approach based on virtual reality, *International Journal of Human-Computer Studies*, 68(5), 254-269.

Campbell, D., & Stanley, J. (1966). Experimental and quasi-experimental designs for research, Chicago, IL: Rand McNally.

Cruz-Neira, C., Sandin, D. J., & DeFanti, T. A. (1993). Surround-screen projection-based virtual reality: the design and implementation of the CAVE. In Proceedings of the 20th annual conference on Computer graphics and interactive techniques, Annaheim, USA.

Felder, R.M., & Silverman, L.K. (1998) Learning and Teaching Styles in Engineering Education, *Journal of Engineering Education*, 78(7), 674-681.

Gardner, H. (2003). Three distinct meanings of intelligence. In Sternberg, R.J. et al., Models of Intelligence: International perspectives (pp.43-54). Washingtong, DC, US: APA.

Häfner, P., Häfner, V., & Ovtcharova, J. (2013). Teaching methodology for virtual reality practical course in engineering education. *Procedia Computer Science*, 25, 251-260.

Hashemipour, M., Manesh, H. F., & Bal, M. (2011) A modular virtual reality system for engineering laboratory education. *Computer Applications in Engineering Education*, 19(2), 305–314.

Impelluso, T., & Metoyer-Guidry, T. (2001) Virtual Reality and Learning by Design: Tools for Integrating Mechanical Engineering Concepts. *Journal of Engineering Education*, 90(4) 527–534.

Isik-Ercan, Z., Kim, B., & Nowak, J. (2012) Can 3D Visualization Assist in Young Children's Understanding of Sun-Earth-Moon System? *International Journal of Knowledge Society Research, 3(4)* 12-21.

Jimeno-Morenilla, A., Sánchez-Romero, J. L., & Salas-Pérez, F. (2013). Augmented and Virtual Reality techniques for footwear. *Computers in Industry*, *64*(9), 1371-1382.

Jou, M., & Wang, J. (2013). Investigation of effects of virtual reality environments on learning performance of technical skills. *Computers in Human Behavior*, 29(2), 433-438.

Kim, K.H. (2006). Can we trust creativity tests? A review of the Torrance Tests of Creative Thinking (TTCT). *Creativity research journal*, 18(1), 3-14.

Kirakowski, J. (1994) The use of questionnaire methods for usability assessment [Online], Retrieved from: http://sumi.ucc.ie/index.html.

Kotler, P., & Armstrong, G. (2010). Principles of marketing. Pearson education.

Lehtonen, M., Page, T., & Thorsteinsson, G. (2005). Emotionality Considerations in Virtual Reality and Simulation Based Learning. In Proceedings of IADIS International Conference on Cognition and Exploratory Learning in Digital Age (CELDA 2005), Porto, Portugal.

Lemole, G.M., Banerjee, P.P., Luciano, C., Neckrysh, S., & Charbel. F.T. (2007) Virtual Reality in Neurosurgical Education: Part-Task Ventriculostomy Simulation With Dynamic Visual and Haptic Feedback, *Neurosurgery*, 61(1), 142-148.

Miyata, K., Umemoto, K., & Higuchi, T. (2010). An educational framework for creating VR application through groupwork. *Computers & Graphics*, 34(6), 811-819.

Nomura, J., & Sawada, K. (2001) Virtual reality technology and its industrial applications, *Annual Reviews in Control*, 25, 99–109.

Ong, S.K., & Mannan, M.A. (2003) Virtual reality simulations and animations in a web-based interactive manufacturing engineering module, *Computers & Education*, 43(4), 361 – 382.

Ritchie, J.M., Dewar, R.G., Robinson, G., Rea, H.J., Day, P.N., & Sung, R.C.W. (2006). User Activity in an Immersive Cable Harness Design System. In 1st International Virtual Manufacturing Workshop (VIRMAN'06), Part of the IEEE VR Conference, Virginia, USA.

Saleeb, N., & Dafoulas, G.A. (2001) Effects of Virtual World Environments in Student Satisfaction: An Examination of the Role of Architecture in 3D Education, *International Journal of Knowledge Society Research*, 2(1), 29-48.

Shen, Y., Ong, S.K., & Nee A.Y.C. (2009) Augmented reality for collaborative product design and development, *Design Studies*, 31(2), 118-145

Stone, R. (2001) Virtual reality for interactive training: an industrial practitioner's viewpoint, *International Journal of Human-Computer Studies*, 55(4), 699-71

Strickland, D. (1997) Virtual Reality for the Treatment of Autism, *Studies in Health Technology and Informatics*, 44, 81-86.

Sutcliffe, A., & Gault, B. (2004). Heuristic evaluation of virtual reality applications. *Interacting with computers*, 16(4), 831-849.

Thorsteinsson, G., & Page, T. (2007) Creativity in technology education facilitated through virtual reality learning environments: a case study, *i-Manager's Journal of Educational Technology*, 3(4), 74-87.

Torrance, E. P. (1974). The Torrance tests of creative thinking-TTCT Manual and Scoring Guide: Verbal test A, figural test. *Lexington, KY: Ginn*.

Torrance, E. P. (1998). The Torrance tests of creative thinking norms — technical manual figural (streamlined) forms A & B.Bensenville, IL: *Scholastic Testing Service, Inc*.

Zwolinski, P., Tichkiewitch, S., & Sghaier, A. (2007) The Use of Virtual Reality Techniques during the Design Process: from the Functional Definition of the Product to the Design of its Structure, *CIRP Annals-Manufacturing Technology*, 56 (1), 135-138.

Appendix A. Satisfaction survey

All questions must be answered. Otherwise, an error be designated to send the questionnaire. Therefore, you must review all questions to ensure that have answered each and every question.

ID	*Question*	*Type of Answer*
1	Practical exercises and activities have facilitated the understanding of the theoretical content	Likert 1-5
2	The objectives were suitable for the expectations and suited the proposed work schedule	Likert 1-5
3	In general, I consider appropriate the methodology used in the various work sessions. I consider it to be beneficial to work with VR devices	Likert 1-5
4	I have had the opportunity to ask questions that arose during the practical sessions	Likert 1-5
5	It would be good to work more with devices since VR facilitates my design comprehension.	Likert 1-5
6	I consider the evaluation criteria understandable.	Likert 1-5
7	I believe that the knowledge I have gained will positively affect my future professional work	Likert 1-5
8	I believe that the use of VR devices has harmed the intern	Likert 1-5
9	Once the training is complete, do you consider the knowledge acquired to have real application in your everyday life?	YES / NO
10	Justify your answer (either affirmative or negative) and describes some specific example. I consider evaluation criteria to be understandable	OPEN
11	Once the training is complete, do you think that the use of VR will help improve your training in Industrial design?	YES / NO
12	Justify your answer (either affirmative or negative).	OPEN
13	Would it mean to you to be a good designer? Justify your answer	OPEN
14	My participation during the practices of the course has been active	YES / NO
15	In general, the practices of the subject have met my expectations	Likert 1-5
16	My motivation and interest during practices have been favourable	Likert 1-5
17	I think this course is a good resource for my professional development	Likert 1-5
18	I think VR techniques have provided me with a good immersive experience	Likert 1-5
19	I believe that VR techniques will be useful in industrial design in the near future	Likert 1-5
20	Use this section to make the observations that you consider appropriate or your overall assessment of the course	OPEN