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Virtual Technologies to Develop Visual-Spatial Ability in Engineering Students

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ABSTRACT
The present study assessed a short training experiment to improve spatial abilities using two tools based on virtual technologies: one focused on manipulation of specific geometric virtual pieces, and the other consisting of virtual orienteering game. The two tools can help improve spatial abilities required for many engineering problem-solving procedures. The results indicated that training activities improved the components of space ability (mental rotation, spatial visualization, and spatial orientation). In addition, it was concluded that there were no differences between men and women with respect to spatial ability levels before or after the training experiment. This fact resulted from masked training relating to daily living and leisure activities that are usually indistinctly performed by men and women in developed and industrialized countries.
Keywords: virtual reality, augmented reality, spatial ability, virtual orienteering, gender

INTRODUCTION

Spatial ability is essential so that engineers can carry out the tasks performed in the profession and also in the academic environment. This ability is an indication of good academic performance in engineering studies (Yue, 2002).

Spatial abilities are an important aspect to be considered in engineering studies. This abilities involves improving students' abstraction ability and helps formulate and solve problems. It allows creating images to perform engineering tasks with greater fluidity. (Adanez & Velasco, 2002).

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State of the literature

- Currently, studies on spatial abilities follow two lines of research to define the factors that compose those abilities. The first one is the proposal of three factors (spatial perception, mental rotation, and spatial visualization) and the second is the proposal of two factors (spatial relation or mental rotation, and visualization). The majority of researchers do not find how to differentiate rotation from orientation. However, recent studies have indicated that this difference was not found because the instruments used to measure orientation were similar to those used to measure rotation (Hegarty & Waller, 2004)
- Numerous authors have proposed different types of training activities to improve spatial ability. Some of these activities, based on multimedia applications and video games, are able to develop and improve spatial abilities. Very few studies have been concerned with developing spatial orientation in a specific way. In general, the studies measure spatial visualization and spatial rotation.
- The differences exhibited by humans in terms of spatial ability levels are due to variables such as: sex; ethnicity; social status; and social environment.

Contribution of this paper to the literature

- We propose the intelligence component "spatial ability" which consists of three sub-factors, namely: spatial relations; spatial visualization; and spatial orientation. Most authors consider that spatial relations and spatial orientation are the same factors, but the error is that they use the same instrument to measure both factors. The Perspective Taking/Spatial Orientation Test, (Kozhevnikov & Hegarty, 2001) provides a way to measure spatial orientation. A good practice is measuring the three components in order to measure spatial abilities.
- A video game platform based on orienteering races and an augmented reality application based on engineering graphics were part of a training proposal for the development and improvement of spatial ability in engineering students. This training experiment was able to improve the levels of spatial ability in men and women in a short period of time.
- Currently, we can consider that there are no differences between men and women with respect to the levels of spatial abilities in those countries in which men and women grow performing all types of activities and not only those relating to their sex.

It is a fact that engineering students have different levels of spatial ability due to various reasons, namely: sex; where they completed secondary education; where they live; and their social environment, among others. These inequalities in spatial abilities influence the different ability of first-year students to understand and assimilate the contents of graphic expression. For this reason, it is suitable that engineering students have a level above the average indicated by the measuring instruments, since having these abilities will help them better understand the contents of engineering (Martin-Gutierrez et al., 2015).

Some universities offer introductory courses—also called zero courses—in certain subjects in order to enhance knowledge. However, it is not enough in the case of graphic expression, since abilities are not taught but trained (Garcia-Dominguez el al., 2015).

High levels of spatial abilities cannot be acquired at any given time. They should be worked over the years of study in the different subjects. In addition, theses abilities should be trained when performing certain tasks relating to leisure, such as sports and video games (Moreau et al., 2012; Subrahmanym & Greenfield, 1994; Feng et al., 2007). In general, that good level also improves the performance of students in engineering programmes (Sorby, 2009a). Lack of spatial abilities in students attending the first year of engineering and other technical fields can make them fail as college students with the consequent student dropout. In Spain, training curricula of all engineering degrees have included the development of spatial visualization in their programmes as a core competence that is necessary to be developed in the students given that it is a significant priority in engineering studies (Spanish Official State Gazette, 2009).

Importance of spatial abilities in engineering studies

Several authors (Wigfield et al., 2007; Zimmerman & Martinez-Pons, 1990) have reported a direct relationship between academic performance, motivational beliefs, and self-regulated learning. They stated that the ability to effectively visualize engineering graphics concepts can affect academic performance. Burton and Dowling (2009) determined that visualization ability—understood as the ability to understand the spatial forms and turn them mentally in two dimensions compared to a model—was a predictor of students' academic success. This fact has also been supported by Potter et al. (2006), who concluded that students' ability to understand three-dimensional spatial relations had influenced their academic success. Both studies have demonstrated that there was a direct relationship between academic performance in engineering studies and spatial abilities.

Knowing students' motivation in engineering graphics subjects is critical to understand the possible problems in retaining students. Dropout rates of engineering students are still a current problem, especially during their first year of college (Sheppard & Jennison, 1997). Students who face numerous problems during the beginning of the academic career may be discouraged and abandon the engineering programme (Sorby, 2009a). According to Sorby (2009a), students with low spatial ability have a high risk of abandoning engineering programmes. Different courses, training exercises and various technologies have been developed to address the lack of spatial abilities (Rafi et al., 2008; Sorby, 2009b).

In engineering graphics, visual thinking serves both as a means of communication with each other and as a tool for personal reasoning. The present study focused on assessing the improvement in spatial ability taking into account three components: spatial relations; spatial visualization; and spatial orientation as a novelty with respect to the other two.

In the following sections, we will discuss a theoretical framework for the identification of spatial ability, most followed theories, and investigations of different types that assess the reasons for inequities in these students' abilities. Subsequently, we will discuss the use of virtual technologies and their relationship with the development of spatial ability. After that, we introduce our purpose about carry out a remedial short course based on virtual technologies for developing spatial abilities in engineering students. Finally, the data will be analysed and the paper will present the results and conclusions.

FRAMEWORK

Spatial ability is a factor of human intelligence and was first identified by Thorndike (1921). He proposed that intellectual functioning was based on three major components and not on a single component as proposed by Spearman, and termed it "singular vision". Thorndike affirmed that Spearman's intelligence tests were "standard", since they only measured "abstract intelligence".

Thorndike included abstract intelligence in his own model of three components, and stressed that the other two components (mechanical and social) of intelligence were equally important. The work of Thorndike (1921) served as a starting point for studies on spatial ability. He defined "mechanical intelligence" as the ability to visualize the relationship between objects and understand how the physical world worked. Thorndike laid the groundwork for the investigation of spatial ability and highlighted the need of creating tools to measure it.

Kelley (1928) and El Koussy (1935) also questioned the basic definition of Sperman's intelligence. El Koussy studied and investigated spatial intelligence and, as a result, developed methods to measure it. El Koussy suggested the existence of a "K" factor, defined as the ability to obtain and use spatial imagination. Kelley also affirmed that the manipulation of spatial relations was another different factor within spatial ability (Miller & Bertoline, 1991).

Thurstone (1938) defined the factor "space" as the ability to mentally operate spatial or visual images. His theory suggests that intelligence consists of several primary mental abilities, rather than a single holistic factor. Thurstone was one of the first scholars to propose and demonstrate these factors through his theory of multiple factors. This theory identified seven primary mental abilities, namely: associative memory; numerical reasoning; speed of perception; reasoning; spatial visualization; verbal comprehension; and verbal fluency. This theory was the basis for creating the intelligence tests that provide a unique measurement for each factor.

Components of spatial ability

Thurstone (1950) identified three primary spatial factors within spatial ability. In further works, the spatial factors defined by Thurstone continued to be used, but the designations were replaced with more descriptive terms (Smith, 1964). Mental rotation was defined as the ability to recognize an object being moved in different directions or angles. Spatial visualization is defined as the ability to recognize the parts of an object when it is moved or displaced from its original position. Spatial perception is defined as the ability to use the own body orientation to interact with the environment and, therefore, with spatial orientation.

After Thurstone, numerous researchers formulated different nomenclatures and definitions for the factors that constitute spatial ability. The disagreement on the nomenclature and definition has been a limiting factor in studies on spatial ability.

Currently, studies on spatial abilities follow two lines of research with respect to the definition of factors. The first one is the proposal of three factors: spatial perception; spatial orientation or mental rotation, considered to be unique; and spatial visualization. The second line is the proposal of two factors: spatial relation, or mental rotation; and spatial visualization.

Some authors consider orientation as perception by defining it as the ability to use the position of the body to resolve issues related to spatial orientation. This way, Smith (1964) suggested that spatial ability consisted of three components: mental rotation; spatial visualization; and spatial perception; which include orientation. Linn and Petersen (1985) and Lohman (1996) claimed that spatial ability was composed of three spatial factors without mentioning orientation; they were: perception; visualization; and relations or spatial rotations.

Pellegrino et al. (1984) and Olkun (2003) considered two components: spatial relations (which included mental rotations and spatial perception) and spatial visualization. Maier (1996) proposed five main components of spatial abilities: spatial relations; spatial perceptions; spatial visualization; mental rotation; and spatial orientation.

Carroll (1993) considered that spatial ability consisted of two sub-abilities: visualization; and mental rotation, defined as:

- Mental rotation is the mental speed to turn simple shapes and recognize them in another position.
- Visualization is the ability to mentally manage complex shapes

Most researchers do not find how to tell the difference between rotation and orientation, although recent studies have demonstrated that this difference was not found because the instruments used to measure orientation were similar to those used to measure rotation (Hegarty & Waller, 2004; Kozhevnikov & Hegarty, 2001; Zacks et al., 2000).

In general, the majority of authors and researchers recognize two factors: mental rotation; and visualization. However, some recent studies that measured spatial abilities have included a third category: spatial orientation (Hegarty & Waller, 2004) as well as a specific instrument for measuring it.

In the present study, we will consider adding a third component—i.e., spatial orientation as defined by Hegarty and Waller (2004)—to the two factors proposed by Carroll (spatial rotation and spatial visualization). We will have the possibility of measuring spatial orientation, because, according to the studies conducted by those authors, spatial orientation and spatial rotation are not identical, even though many authors affirm they are.

RESEARCH IN THE FIELD OF SPATIAL ABILITIES

The goal of studies assessing the development of spatial ability is to answer questions relating to when and how space ability develops. These questions have promoted lines of works addressing the differences in the development or acquisition of spatial abilities with respect to sex, ethnicity, social status, age, environment, materials, instruments, and technologies used for improvement.

Spatial ability and age

Piaget and Inhelder (1971) indicated that spatial ability develops from childhood to adulthood in three stages. In the first stage, children acquire two-dimensional abilities and learn the relationship between objects. During the second stage, children learn how to manage three-dimensional objects training orientation and rotation abilities. In the third stage, individuals learn to relate two-and three-dimensional spaces (transition from projective space to Euclidean space) bearing in mind, identifying and controlling concepts such as parallelism, proportion, area, volume, and distance.

Halpern & LaMay, (2000) concluded that age affects the level and improvement of space ability in the individuals, i.e., there is more resistance to improve space ability as individuals get older. According to Flanery and Balling (1979) and Orde (1996), spatial ability improves with age during childhood years, decreases with age, and there is greater resistance to improve it in adulthood (Lawton, 1994; Macnab and Johnstone, 1990; Pak, 2001). Age-related differences are often the result of differences in processing speed, knowledge, and experience (Salthouse, 1987). Núñez et al. (1998) affirmed that age influenced accuracy when solving any type of problems.

Differential research

The literature constantly mentions differences in levels of spatial ability between men and women, often recognising male superiority. Maccoby and Jacklin (1974) have generated increased interest in this issue indicating four areas in which there are differences between men and women, the most notable being spatial ability. In addition, several researchers have conducted specific studies that highlighted the difference in levels of spatial ability according to sex (Harris, 1978; Linn & Petersen, 1986; Lohman, 1979; McGee, 1979; Nyborg, 1983; Voyer, Voyer & Bryden, 1995).

Studies on the difference between men and women are considerably wide and that difference is one of the most controversial issues addressed by studies on spatial ability. In general terms, men perform better than women in spatial tasks (particularly rotations), spatial perception, mathematical reasoning, and ability to focus. On the other hand, women perform better than men in verbal fluency, speed of perception, memory, and certain motor skills (Kimura, 1996).

There are also studies indicating that differences in spatial abilities between men and women are narrowing. These studies also claim that, in some cases, the differences do not exist at all (Brownlow, 2002; Caplan et al., 1985, 1986; Fennema & Sherman, 1977; Hyde, 1981; Linn & Hyde, 1989; Lohman, 1996; Lord & Garrison, 1998; Michaelides, 2003).

Differences between men and women in spatial perception

Spatial perception is closely associated with orientation. Some studies refer to spatial perception as orientation. These studies have indicated that individuals who live in open environments and perform outdoor activities have greater spatial ability (Gardner et al., 1960; Manfredo, 1987; Miller, 1992c; O'Brien, 1991; Podell & Phillips, 1959; Sherman, 1974; Study, 2002; Thurstone, 1944). In addition, they have concluded that men perform better than women in tasks that require spatial perception (Linn & Petersen, 1985; Witkin, 1950; Sherman; 1974, Witkin el al., 1977; Miller, 1992; Dwyer & Moore, 1998).

Differences between men and women in spatial ability

Differences between men and women in spatial ability also favour men and it occurs almost in all countries, classes, ethnicities, and ages (Eals & Silverman, 1994). Male superiority is more pronounced in mental rotation tasks. There are minor differences in orientation between men and women and there are no evident differences in spatial visualization (Harris, 1978; Linn & Peterson, 1986; Stumpf & Kieme, 1989). Most researchers have recognised that the differences between men and women only appear in a reliable manner after puberty, and that those differences can be developed during adulthood, (Nyborg, 1983).

Some studies have recognised the effect of hormones on space ability, indicating that oestrogen negatively affects spatial ability, whereas testosterone does not affect it (Harris, 1978; Kimura, 1996; McGee, 1979; Moffat & Hampson, 1996; Nyborg, 1983). In addition, some of these studies have also affirmed that hormones were the primary reason why differences between men and women arise.

Differences between men and women in spatial orientation

There is a widespread stereotype suggesting that women have greater difficulty than men in tests that imply the sense of orientation. The truth is that researchers have not found scientific evidence to support this stereotype. Beaumont et al. (1984) did not find differences between men and women moving around a building which had a complex structure and was unknown to them. Similar studies conducted by Montello et al (1999) and Montello and Pick (1993) found no evidence of differences in spatial orientation between men and women in the tests to which the participants had been subjected.

On the other hand, there are studies that have found different results from the previous ones, indicating that men perform better than women in spatial orientation (Galea & Kimura, 1993, Malinowski & Gillespie, 2001; Waller et al., 2001). There are also other studies which have found differences between men and women (Sadalla & Montello. 1989; Brown et al., 1998). For this reason, it is not possible to confirm the existence of differences between men and women in spatial orientation. Therefore, it is possible to continue claiming that male superiority in spatial orientation is a stereotype. Gonzalez-Roca (2016) has presented a collection of experimental studies on sex-related differences in spatial orientation.

SPATIAL ABILITY AND VIRTUAL TECHNOLOGIES

Augmented reality is a variant of virtual reality in which the users are immersed in scenarios created with computer technologies. While immersed in the virtual reality system, users cannot see the real world that surrounds them. On the other hand, augmented reality allows users to see the real world, with virtual objects overlapped or combined with them. Therefore, augmented reality complements the reality rather than replacing it. The goal of this technology is to ensure that users have the feeling that real and virtual objects coexist in the same space, which is similar to the effects of the films "Who framed Roger Rabbit" and "Space Jam", although they are not characterised as augmented reality technology.

According to Barfield and Caudell (2001), the concept of augmented reality refers to "The extension of the real world by means of synthetic images, due to which it is not required that the scene is completely generated by a computer; however, the synthetic image is used as a complement to the real-world scenes". The authors added that "Augmented reality should not be understood as only visual; it should also include tactile, tangible, and auditory information". Augmented reality systems can add sensory elements to the physical reality, such as images, virtual models, sounds, etc. Some parts of reality can be also altered using filters. Besides adding or altering, there is a third possibility, such as the case of diminished reality, which allows removing items from the real environment using masks that hide physical objects (Herling & Broll, 2012, 2014).

According to Sherman and Craig (2003), augmented reality systems have different constraints in systems design compared to virtual reality systems. While the goal of virtual reality is the visualization of enough faces or surfaces so that the created environment is credible, the world already exists in augmented reality, and it is only necessary to add a small amount of information. Thus, the challenge of augmented reality is to produce independent and portable systems, which should be able to accurately register or locate the virtual environment into the real environment. According to Azuma et al. (2001), an augmented reality system should simultaneously contain three features:

- Mix of reality and virtuality.
- Real-time interactivity.
- Three-dimensional registration.

In the present study, we used augmented reality and virtual reality technologies as a means to improve students' spatial abilities due to their proven motivational impact on learning (Martin-Gutierrez & Meneses, 2014; Di Serio et al., 2013; Lee et al., 2010) and also because they facilitate student-centered learning (Di Serio et al., 2013; Larsen et al., 2011).

We can find many experiences with augmented reality and virtual reality in different educational levels, from early stages of education (day care centers), where children were motivated to learn, enjoyed the experience and exhibited curiosity, refusing to stop the activities until they were completed (Campos et al., 2011), to cases such as those studied by Thornton et al. (2014) and Tumkor et al. (2013) who concluded that including augmented reality in engineering graphics courses increased students' interest and motivation.

There are some courses based on virtual technologies to improve spatial abilities, specifically visualization and rotation (Martin-Gutierrez et al., 2010, 2015; Regian et al., 1992; Dünser et al., 2006).

In order to exercise spatial orientation, various researchers have conducted experiments ranging from searches for treasures in open environments (Hegarty et al., 2006; Montello et al., 1999) to experiences of virtual navigation using various tests (Dahmani et al., 2012; Darken & Goerger, 1999; Lin et al., 2014).

Researchers have observed that it is possible to develop spatial abilities (visualization, rotation, and orientation) in virtual worlds. However, there is few studies that allows knowing whether the experience that individuals acquire in virtual environments lead them to have a similar behavior in the real world and in similar circumstances.

A study conducted by McKinnon and North, (2004) compared users' feeling of presence in virtual scenarios with the feeling of presence in the real world. The results revealed an interesting preliminary theory indicating that users felt better within virtual environments, because they felt that they had better control over the space.

METHOD AND EXPERIENCE

Purpose

The purpose of this work was to conduct a short training experiment using virtual technologies (virtual reality and augmented reality) to improve the components of spatial ability, namely: spatial relations; spatial visualization; and spatial orientation in new engineering students at University of Las Palmas de Gran Canaria, Spain. In case of obtaining positive improvement results, this training experiment will help students have minor difficulties in their studies and obtain best academic results.

Tools for training

The training experiment consisted in performing activities using two platforms, one of augmented reality, whose purpose was to perform tasks relating to spatial relations and spatial visualization, and the other of virtual reality with the purpose of performing tasks relating to spatial orientation.

Augmented reality platform

The augmented reality platform is an application software associated with a three-dimensional interactive book titled "Virtual Augmented Book" (**Figure 1**) that allows visualising three-dimensional objects and complete the proposed tasks. The software and the "Augmented Book" for the training experiment were created by the authors of the present study and is available at www.ar-books.com.

The content proposed in the Augmented Book is an effective way for improving spatial abilities when students have to complete tasks. This set of activities contributes to the development of the spatial factor. This didactic material was created using Bloom's taxonomy (Anderson & Krathwohl, 2001). It consisted of five levels (knowledge, comprehension, application/analysis, synthesis, and evaluation) and each one of them contained several types of exercises. Each level had a duration of two hours, with exception of level 5 (evaluation), in which six exercises should be completed in just one hour without the help of any model.

The training experiment was organized into five sessions with a total duration of nine hours (four sessions of two hours and a final session of one hour). Students could access the three-dimensional model in augmented reality (Augmented Book) and check whether their freehand sketches corresponded to the three-dimensional virtual models that they were visualising.

- Level 1 (Knowledge): The students had to identify surfaces and vertexes on both orthographic and axonometric views of a three-dimensional virtual object created in the Augmented Book (contained three types of tasks).
- Level 2 (Comprehension): The students had to identify orthographic views of three-dimensional virtual models in the exercise book (contained two types of tasks).
- Level 3 (Application/Analysis): The students had to identify the spatial relation between objects. This was carried out by means of "recount" exercises in which students were asked to identify how many objects were in touch with one selected object. There were also exercises in which the students had to select the minimum number of views to completely define an object (contained two types of tasks).
- Level 4 (Synthesis): It had greater difficulty than the previous levels. There were exercises in which the students had to sketch the missing orthographic view. Knowing two orthographic views of a model and using the virtual model as the only input, they had to sketch all the orthographic views (contained two types of tasks).
- Level 5 (Evaluation): The exercises were the most difficult, because they required a greater level of spatial ability. Students were provided with three orthographic views of each object, and they had to build the corresponding three-dimensional model in their minds and then draw a freehand perspective of it. The students had one hour to complete six exercises, without any help of virtual models. This level was used to assess

students' progress. The proposed isometric drawings could be checked after completion.

Figure 1. Augmented reality platform to train spatial abilities.

Virtual reality platform

Training by means of a virtual environment requires less effort than the same training performed in the real environment. Performing a test of orientation in individuals with some degree of disability requires great caution with respect to their safety. Even in participants who do not have any kind of disability, the experience may fail as a result of any unexpected discomfort or accident of the participants. For this reason, virtual environments can be a good alternative to avoid these risks. (Darken & Banker, 1998).

The virtual reality platform used to train spatial orientation was Catching Features (http://www.catchingfeatures.com). It is a computer orienteering game in which one or more players are immersed in a virtual environment and run races using a topographic map and a compass, as if it were a real races.

Figure 2. Catching Features scenarios

The platform allows playing individually or competing with other participants. The scenarios are very realistic and the players can move with a view from and towards all directions. They can locate landmarks using the map and the compass until completing the proposed route.

In our experiment, we asked the students to complete a minimum of six races with different length and scenarios. They were advised to perform one race per day and they could do it at any time and place.

Catching Features provided the results obtained in the various races, indicating the times spent to reach each landmark and the total duration of the race. The professor asked the students the files of results in order to verify and assess the performance of the experiment and provide the incentives promised to the students (in this case, they received an extra mark in the final examination of the course).

Figure 3. Example of students' results.

Instruments to measure the components of spatial ability

The different lines of research in the field of psychology have provided numerous instruments (tests) to measure and assess the different factors of spatial ability. With the passage of time, some of these instruments have become standardized tests of a commercial nature.

Martin-Gutierrez (2010) presented a compilation of the tests used to measure spatial relations and spatial visualization. Cristina Roca (2016) complemented this compilation with the tests available to measure spatial orientation.

To measure the components of spatial abilities, we followed the classification proposed by Carroll (1993) and the classification proposed by Kozhevnikov and Hegarty (2001) to measure spatial relations and spatial visualization, in addition to spatial orientation.

The tools used to measure each of the components were: Mental Rotation Test (MRT) (spatial relations); Differential Aptitude Test (DAT-5: SR) (spatial visualization); and Perspective Taking/Spatial Orientation Test (PT/SOT) (spatial orientation). We chose these instruments in order to follow the criteria used in previous national and European studies, and because these instruments are used to measure these components in other fields of knowledge at the international level. This homogeneity may allow comparing results if necessary.

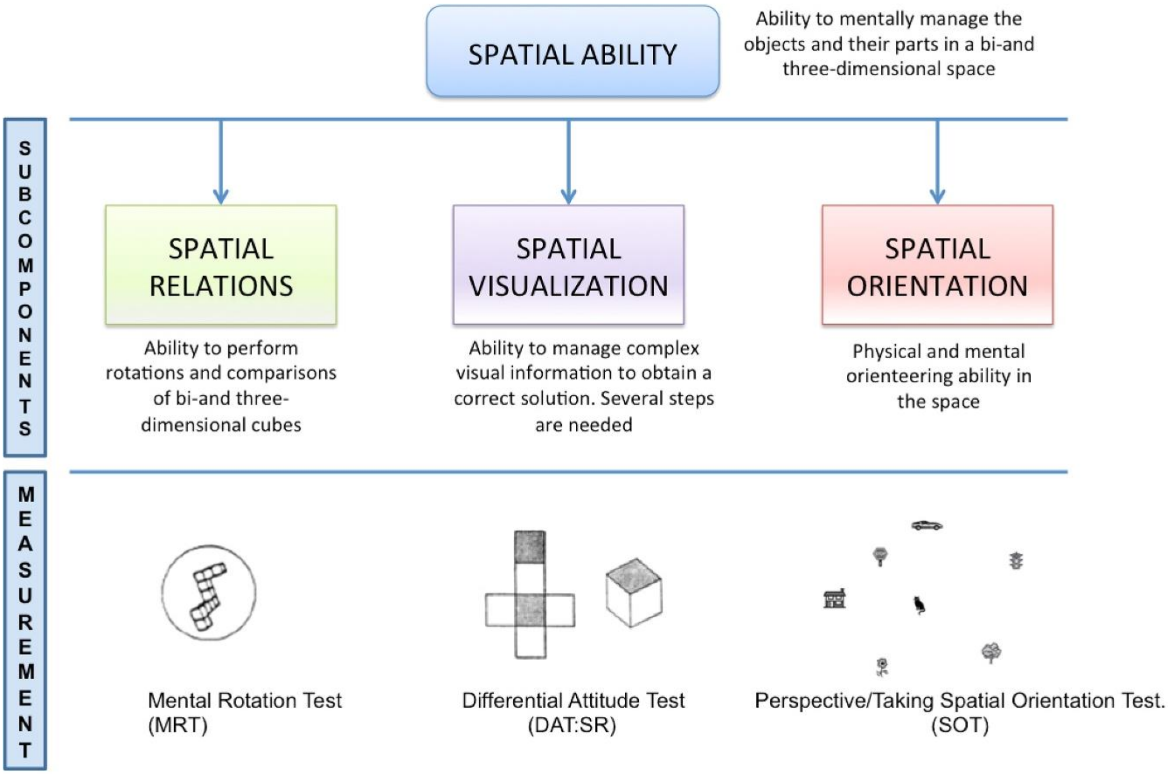

Figure 4. Subcomponents and test for measuring the spatial factor.

The MRT contains 20 items. Each item has a model of a block in three-dimensional perspective. Then, the test shows four figures of blocks in three-dimensional perspective with a different rotation. Two of these figures match the model, but they are shown in a rotated position. The other two figures are blocks differing from the model. **Figure 5** shows an example of one MRT item.

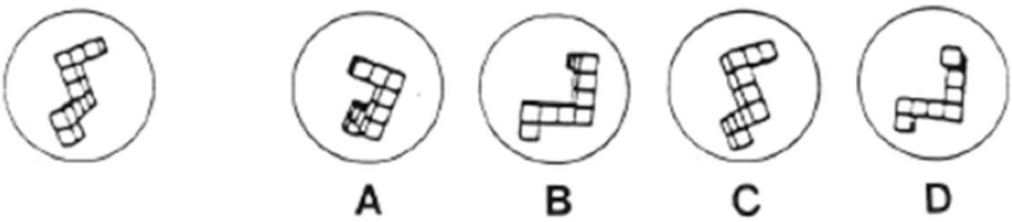

Figure 5. Examples of Vandenberg Mental Rotation test (Vandenberg, 1978).

The DAT-5: SR consists of 50 items. Each of them presents a model or pattern of an object displaying all its faces. There are also four three-dimensional figures, of which only one corresponds to the pattern when its faces are displayed. **Figure 6** shows an example of one DAT-5: SR item.

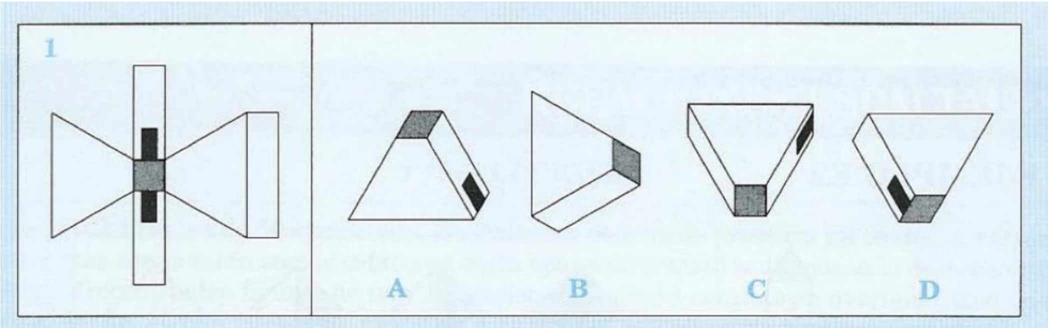

Figure 6. Example of the DAT-5:SR.

The PT/SOT consists of 12 items. Each item at the top represents a set of seven objects. There is a circle at the bottom in which a direction is indicated. In each item, the user should imagine they are situated at the location of one of the objects of the set (which will be in the center of the circle), looking at another one of them (which will be at the top of the circle as if it was 12 o'clock). The participants should draw an arrow from the central object indicating the direction towards a third object from the new orientation. The score for each item is the absolute deviation measured in sexagesimal degrees between the response of the individuals and the correct answers. In this way, a lower score in the test corresponds to a greater success. The total score will be the average deviation of the absolute directional errors in the 12 established positions. A value of 90° will be assigned in case one of the questions is not responded (Figure 7).

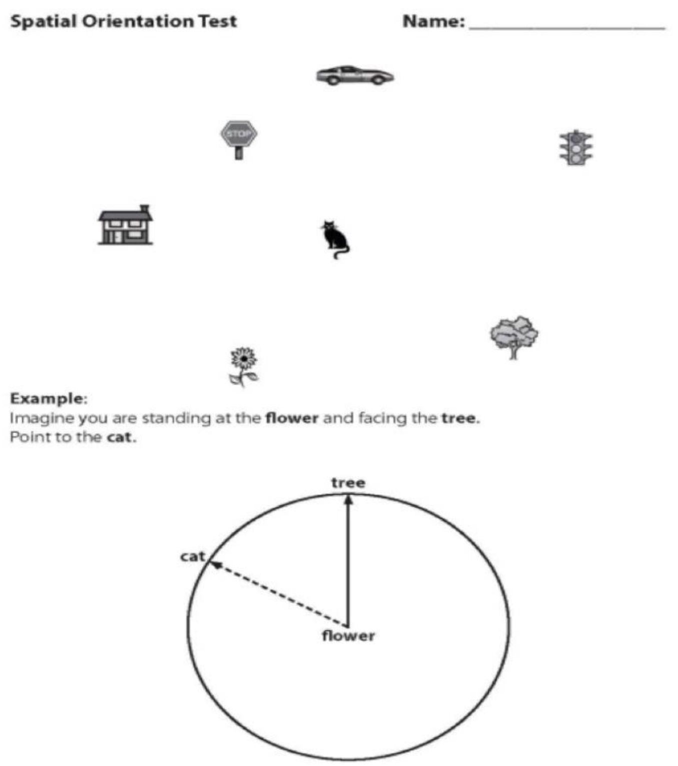

Figure 7. Example of Perspective Taking/Spatial Orientation Test

Selection and description of participants

At the beginning of the academic year (October), volunteers were selected among students enrolled in Civil Engineering Studies to take part in a spatial ability improvement training experiment.

Spatial abilities were measured (MRT, DAT-5:SR, and PT/SOT) in a total of 178 first-year Mechanical, Electronic and Civil Engineering students at the University of Las Palmas de Gran Canaria (Spain).

The training group consisted of 15 individuals, of whom eight were men and seven women aged between 18 and 20 years. The control group did not carry out the training experiment and it consisted of 16 individuals, of which 11 were men and five women aged between 18 and 20 years. None of students of the two groups participating in the experiment had prior training in spatial ability or practice in spatial orientation. **Table 1** shows the level of spatial abilities of the total population, the experimental group, and the control group prior to the training experiment with augmented reality.

Table 1. Mean scores, standard deviation (SD), and number of cases (n) in the pre-test for measuring Students' spatial ability.

	Total Population (n = 178) Mean (SD)	Experimental Group (n = 15) Mean (SD)	Control Group (n = 16) Mean (SD)
Pre-MRT	15.22 (7.30)	17.20 (8.00)	13.37 (6.27)
Pre-DAT-5:SR	24.90 (10.95)	26.73 (11.65)	23.19 (10.32)
Pre-PT/SOT	26.26 (29.75)	51.52 (24.87)	60.70 (33.91)

Note. MRT = Mental Rotation Test; DAT-5: SR = Differential Aptitude Test; PT/SOT = Perspective Taking/Spatial Orientation test; SD = standard deviation.

Design and procedure

The experiment was conducted during the first and second week of the first semester. This way, when the students participated in the experiment, none of them had attended classes of graphic expression in engineering.

During the first week, the experimental group performed the training activities using the augmented reality platform. The first day (Monday), after completing the pre-test for measuring spatial ability, we explained the goal of the training experiment and the material available to perform it. We also provided supplementary information indicating that one level of training, with a duration of less than two hours, would be carried out each day; however, they should perform it on an ongoing basis, i.e., without pauses during the performance of the level. The training experiment consisted of five levels of exercises, so that it would end on Friday and the students would rest over the weekend. It was an autonomous training and the students could perform it at the time and using their own computers.

In the second week (Monday), we explained the material available to continue the training experiment. The explanations included the principles of orienteering sports, the use of the compass, how to read maps, and the operation of the software (Catching Features). This part of the training experiment consisted of six orienteering races to be performed one per day. The training experiment was completed at the end of the second week and the test for measuring the levels of spatial ability was again applied to the experimental and the control groups (relations, visualization, and spatial orientation). In addition, the professors had a very positive feedback from the students who considered that the experiment was very interesting and useful for dealing with the subject.

DATA ANALYSIS AND RESULTS

The goal of the present study was to assess whether the students improved the components of spatial ability after performing the proposed training experiment. The hypotheses to be confirmed were:

• Hypothesis 1: The two groups (experimental and control) will significantly improve spatial visualization measured with the DAT-5: SR after performing the proposed training experiment.

• Hypothesis 2: The two groups (experimental and control) will significantly improve spatial relations measured with the MRT after the proposed training experiment.

• Hypothesis 3: The two groups (experimental and control) will significantly improve spatial orientation measured with the PT/SOT after performing the proposed training experiment.

• Hypothesis 4: Improvement in spatial visualization is acquired to the same extent in men and women.

• Hypothesis 5: Improvement in spatial relations is acquired to the same extent in men and women.

• Hypothesis 6: Improvement in spatial orientation is acquired to the same extent in men and women.

The mean values of the MRT, DAT-5: SR, and PT/SOT in the experimental and control groups, obtained prior to the training experiment, were very similar to those of the total population (**Table 2**).

We used Kolmogorov-Smirnov test with Lilliefors' significance correction to check the normality of the samples. The hypothesis were:

• Null hypothesis (H0): The score of the test applied before the training experiment belongs to a normal population with unknown mean and variance.

• Alternative hypothesis (H1): The score of the test applied before the training experiment does not belong to a normal population with unknown mean and variance.

Table. 2. Test for normality of variables in the experimental group and the control group.

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistical	**gl**	**Sig**	**Statistical**	**gl**	**Sig**
Exp. Group	**Pre-MRT**	.142	15	.200*	.915	15	.159
	Pre-DAT-5:SR	.185	15	.178	.900	15	.095
	Pre-PT/SOT	.116	15	.200*	.963	15	.747
Control Group	**Pre-MRT**	.150	16	.200*	.958	16	.624
	Pre-DAT-5:SR	.142	16	.200*	.938	16	.321
	Pre-PT/SOT	.159	16	.200*	.945	16	.420

*Note. *Lower limit of real significance; aLilliefors significance correction*

The null hypothesis of normality (p-value >0.05) was accepted. It indicated that the two samples (experimental and control) were representative of the total population. **Table 3** summarises the result of the analysis that indicated whether there were significant differences in the levels of MRT, DAT-5: SR, and PT/SOT in three groups (total population, experimental group, and control group) prior to the training experiment.

Levene's test for equality of variances and the t test for equality of means indicated that there were no significant differences between the groups prior to the training experiment ($F_{2.178} = 1.508$, $p = 0.229$ in MRT; $F_{2.178} = 0.216$, $p = 0.646$ in DAT-5:SR; and $F_{2.178} = 2.334$, $p = 0.138$ in PT/SOT). The p-value was >0.05 in all the cases. In other words, all the groups were statistically equivalent in spatial visualization, spatial relation, and spatial orientation before the training experiment.

Table 3. Results of the analysis for assessing whether there were significant differences between the groups.

		Levene's test for equality of variances		*t*-test for equality of means						
		F	**Sig**	***t***	**gl**	**Sig. (bil)**	**Diff. in means**	**Typical error of the diff.**	**95% confidence interval for the differences**	
									Lowest	**Highest**
Pre-MRT	Assumption of equal variances	1.508	.229	-1.48	29.0	.14	-3.82	2.572	-9.086	1.4369
	No assumption of equal variances			-1.47	26.5	.15	-3.82	2.593	-9.150	1.500
Pre-DAT5:SR	Assumption of equal variances	.216	.646	-.89	29.0	.37	-3.54	3.947	-11.620	4.528
	No assumption of equal variances			-.89	28.0	.37	-3.54	3.963	-11.665	4.573
Pre-PT/SOT	Assumption of equal variances	2.332	.138	.85	29.0	.40	9.17	10.741	-12.795	31.144
	No assumption of equal variances			.86	27.4	.39	9.17	10.634	-12.628	30.978

After the completion of the training experiment, spatial abilities were measured again. **Table 4** shows the results of the pre-and post-tests and the gain scores.

Table 4. Means of the pre-and post-test and gain scores (standard deviation).

	Pre-MRT Mean (SD)	Post-MRT Mean (SD)	Gain Scores MRT Mean (SD)	Pre-DAT-5:SR Mean (SD)	Post-DAT-5:SR Mean (SD)	Gain Scores DAT-5:SR Mean (SD)	Pre-PT/SOT Mean (SD	Post-PT/SOT Mean (SD)	Gain Scores PT/SOT Mean (SD)
Participants n = 15	17,20 (8,00)	25,06 (8,68)	7.87 (4.3)	26,73 (11,65)	36,26 (8,89)	9,53 (5.9)	51,52 (24,87)	25,06 (15,46)	26.46 (17.48)
Standard error of the mean (SEM)	**2,06**	**2,24**	**1.04**	**3,01**	**2,29**	**1.548**	**6,42**	**3,99**	**4.51**
Control Group n = 16	13,37 (6,27)	17,62 (7,60)	4.25 (3.19)	23,18 (10,32)	28,12 (10,26)	4.93 (3.62)	60,70 (33,91)	47,13 (34,27)	13.57 (9.23)
Standard error of the mean (SEM)	**1,57**	**1,90**	**0.79**	**2,58**	**2,56**	**0.90**	**8,48**	**8,57**	**2.30**

Note. MRT = Mental Rotation Test; DAT-5: SR = Differential Aptitude Test; PT/SOT = Perspective Taking/Spatial Orientation test; SD = standard deviation.

We assessed whether the gain values were significant for the improvement of the spatial ability components, i.e., whether the values obtained after the training experiment were different from the values obtained before the experiment from a statistically significant point of view.

Firstly, we used Kolmogorov-Smirnov test with Lilliefors' significance correction to assess whether the variables were distributed according to normality (**Table 5**).

Table 5. Test of normality for gain in the experimental and control groups.

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistical	**gl**	**Sig**	**Statistical**	**gl**	**Sig**
Experimental Group	**Gain - MRT**	.180	15	.200*	.945	15	.456
	Gain - DAT-5:SR	.095	15	.200*	.961	15	.707
	Gain - PT/SOT	.186	15	.173	.925	15	.231
Control Group	**Gain - MRT**	.219	16	.039	.876	16	.033
	Gain - DAT-5:SR	.181	16	.171	.895	16	.068
	Gain - PT/SOT	.127	16	.200*	.939	16	.343

*Note. * Lower limit of real significance; [a]Lilliefors significance correction.*

The null hypothesis of normality for these variables was accepted, because all the probabilities associated with statistical contrast were greater than 0.05, except for the gain in the control group measured using the MRT, for which we applied Pearson's chi-square test, whose hypothesis were:

- Null hypothesis (H_0): The gain in the control group measured using the MRT belonged to a normal population with unknown mean and variance.
- Alternative hypothesis (H_1): The gain in the control group measured using the MRT did not belong to a normal population with unknown mean and variance.

The chi-square test showed a p-value of 0.544. Therefore, the null hypothesis could be accepted assuming that the gain in the control group measured with the MRT was also distributed according to normality.

Subsequently, we used the t-test for independent samples and normal variables with unknown but equal variances in order to assess the six hypotheses indicated at the beginning of this section. Hypotheses 1 to 3 are defined as:

- Null hypothesis (H_0): Score gain in the tests (MRT, DAT-5: SR, and PT/SOT) is the same in the experimental group and the control group.
- Alternative hypothesis (H_1): Score gain in the tests (MRT, DAT-5: SR, and PT/SOT) is different between the experimental group and the control group.

Table 6 summarises the results of the analysis indicating that the p-value associated with the gain in the MRT, DAT-5: SR, and PT/SOT tests was less than 0.05, which led us to reject the null hypothesis. Therefore, it was demonstrated that there were significant differences between the experimental group and the control group. Therefore, it can be affirmed that the training experiment improved the three components of spatial ability in the students.

Table. 6. Test for independent samples. Gain in the MRT, DAT-5: SR, and PT/SOT tests.

		Levene's test for equality of variances		*t*-test for equality of means						
		F	**Sig**	***t***	**gl**	**Sig. (bil)**	**Diff. in means**	**Typical error of the diff.**	**95% confidence interval for the differences**	
									Lowest	**Highest**
Gain MRT	Assumption of equal variances	.671	.419	-2.77	29	.010	-3,61	1.302	-6.28	-.953
	No assumption of equal variances			-2.75	26.69	.010	-3.61	1.312	-6.31	-.922
Gain DAT5:SR	Assumption of equal variances	4.55	.041	-2.60	29	.014	-4.59	1.766	-8.21	-.982
	No assumption of equal variances			-2.56	22.73	.018	-4.59	1.794	-8.31	-.881
Gain PT/SOT	Assumption of equal variances	13.0	.001	-2.59	29	.015	-12.89	4.976	-23.1	-2.711
	No assumption of equal variances			-2.54	20.94	.019	-12.89	5.071	-23.4	-2.341

Subsequently, we assessed whether there were differences in the gain values with respect to sex. **Table 7** shows the values obtained by the men and women that participated in the training experiment.

Table 7. Descriptive statistics. Gain and Sex.

	Sex	N	Mean	Standard deviation	Typical error of the mean
Gain MRT	**Men**	19	6.368	3.947	.905
	Women	12	5.416	4.209	1.215
Gain DAT-5:SR	**Men**	19	6.736	5.194	1.191
	Women	12	7.833	5.797	1.673
Gain PT/SOT	**Men**	19	17.893	14.356	3.293
	Women	12	22.837	16.397	4.733

Considering that the variances were equal, **Table 8** shows the results indicating that the *p*-value was greater than 0.05. Therefore, there were no significant differences between men and women in the improvement of spatial abilities after the training experiment.

Table 8. Test for independent samples. Gain and sex in the MRT, DAT-5: SR, and PT/SOT tests.

		Levene's test for equality of variances		*t*-test for equality of means						
		F	Sig	t	gl	Sig. (bil.)	Diff. in means	Typical error of the diff.	95% confidence interval for the differences: Lowest	95% confidence interval for the differences: Highest
Gain MRT	Assumption of equal variances	.120	.732	.638	29	.529	.951	1.492	-2.101	4,005
	No assumption of equal variances			.628	22.39	.536	.951	1.515	-2.187	4,091
Gain DAT5:SR	Assumption of equal variances	.073	.789	-.54	29	.588	-1.096	2.002	-5.192	2.999
	No assumption of equal variances			-.53	21.59	.599	-1.096	2.054	-5.361	3.168
Gain PT/SOT	Assumption of equal variances	.125	.726	-.88	29	.384	-4.944	5.591	-16.379	6.490
	No assumption of equal variances			-.85	21.19	.401	-4.944	5.766	-16.930	7.041

CONCLUSION

In many university systems, like in the Spanish one, there is a growing diversity in the curriculums that the students have to follow before entering the undergraduate level. In the case of subjects relating to engineering graphics, many students have a poor background on this matter and also underdeveloped cognitive skills for dealing with graphic information in their minds.

On the one hand, the evolution of technology and the appearance of new teaching techniques have made some methodologies obsolete, because they are not properly adapted to modern trends. Teaching methods should evolve and be adapted to the new technologies that students are used to. This way, students will clearly benefit from this learning. On the other hand, students are digital natives. They are used to all types of electronic devices and manage information in many digital platforms. Traditional teaching methodologies can cause boredom and lack of motivation during the teaching activities. In many cases, this fact represents a serious handicap to engage the students in paper-and-pencil-based exercises.

In this context, engineering professors should be continually looking for strategies to implement the most effective instructional approaches. Virtual technologies and video games can provide important potential tools. The use of specific video games as a complementary activity to classical academic tasks can promote students' motivation and a positive attitude, as we have noted during the conduction of the present study.

We consider that there are two basic approaches to integrate virtual technologies or video games as a complementary activity in the specific context of spatial ability development. One is based on assessing available commercial titles, as the tool presented in the present study (Catching Features). Tools available on the Internet are a solution to create a compelling environment for the development of spatial abilities. The other approach would be developing *ad hoc* applications that combine the appearance and feeling of video games with some contents relating to engineering graphics, like applications based on augmented reality used in the present study.

In engineering graphics, when paper-and-pencil-based exercises are proposed, there is a risk that students do not perform them due to boredom, lack of motivation and for being unattractive tasks. For this reason, the contents and tasks for the development of spatial abilities should be supported by activities and tools that attracts students' attention, even after training activities. In addition, so that the tasks do not become a routine and students lose interest in the course and in the technology used, training must be of short duration, offering different types of exercises or different training scenarios.

Augmented reality is a technology that provides attractive contents compared to paper books. It gives new life to classical paper-and-pencil-based exercises. In educational applications, it is of utmost importance to focus attention on the current task in order to reduce the cognitive overload needed to use the application. This fact motivated us to design a user-friendly system and a friendly and agreeable environment. This augmented reality application has proven to be an efficient and effective material for developing spatial abilities and learning engineering graphics contents.

With respect to virtual environments, it should be kept in mind that despite the realism they can offer, the real world will always give us more information and feelings and will be more intense. Moving in a virtual environment, such as an avatar, will always be a passive activity, although it is true that the feeling of immersion can be almost real.

The proposed training experiment improved the components of spatial ability. In addition, it provided basic knowledge about graphic representation in engineering through the activities proposed in the augmented reality using orthographic views and perspectives.

In the present study, we measured the improvement in spatial ability of engineering students as a consequence of specific training activities based on virtual technology. We measured three components of spatial ability. Despite the numerous theories that propose two components (spatial relations and spatial visualization), we included spatial orientation, because some authors consider that it is not included in spatial relations. In fact, there are few studies that address spatial orientation, because authors traditionally followed do not include this component.

The proposed training experiment improved the three components of spatial ability. Augmented reality exercises influenced visualization and rotation, whereas the game of orienteering races improved spatial orientation.

Improvement results showed that there was no difference in spatial ability levels according to sex. This result may be due to the fact that, in developed and industrialized countries, children grow in an environment in which boys and girls perform the same types of tasks and games. The classic roles of games/activities for boys or girls tend to disappear. It is common to see girls playing football, basketball, or video games, which was uncommon a few years ago. These tasks, which in some way (unconsciously) were related to training men's spatial abilities, are also performed by women.

In addition to the abovementioned, in general terms we can affirm that:

- Training by means of orienteering video games is the strategy that improves spatial abilities. However, it does not enhance knowledge about graphic design. Therefore, it does not provide learning opportunities for the students.
- Training carried out with augmented reality can be performed autonomously, given that the material allows this possibility. In addition, these types of training activities enhance knowledge about graphic design. Therefore, it provides learning opportunities for the students.
- A short course of approximately 16 hours for developing spatial ability in engineering students significantly improves spatial visualization levels.

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