Training of Spatial Ability on Engineering Students Through a Remedial Course Based on Augmented Reality

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TRAINING OF SPATIAL ABILITY ON ENGINEERING STUDENTS THROUGH A REMEDIAL COURSE BASED ON AUGMENTED REALITY

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Spatial Skill, Augmented Reality, Engineering Education, Academic success

ABSTRACT
This paper presents the results of a study designed to evaluate the effect of attending an intensive remedial course based on desktop augmented reality exercises to improve the spatial ability of freshman engineering students. Many of these students have problems in managing visual information or in creating mental models of objects represented by their orthographic projections. The study reports about research on comparison tests about the spatial skills of engineering students from two Spanish universities before and after performing a specific training for improving these abilities. The training was completed by 66 students as participants, considering a control group composed of 25 students from both universities. Results show that students from both universities improve their spatial ability and there is no statistical significance between students from both universities, neither before nor after training, so we may conclude that training's effect on both universities is analogue.

INTRODUCTION
Several studies pointed out that good level of spatial skills are a key aspect for success in engineering degrees as well as professional careers [1, 2]. An engineer should be capable of creating a mental image of an object and see mentally the different perspectives of it for finding out the relations between this object and another one or any other person in space. These skills are very important in the whole process design since the starting phase until the final prototype so improvement of spatial abilities and their successful application is an important research theme on engineering education.

The last years, numerous experiences about fast remedial courses to improve spatial abilities of engineering students had been made. In these courses different tools have been tried out: classic exercises (views) using pen and paper, online multimedia web-based exercises, sketch-based modeling through a calligraphic interface,[3] use of the Google Sketch-up modeling application [4] and videogames as a work tool [5]. The target is that students who take part in these courses will improve their spatial abilities so it will help them for a better understanding of the contents of the 'Engineering Graphics' subject.

Acquiring this ability can be done through an indirect process by means of Engineering Graphics subjects where students perform sketching tasks to create and read orthographic and axonometric projections [6]. However, there is another approach based on the development of specific training for the development of spatial skills.

From our perspective as teachers, we realize what difficulties the first year engineering students experience while learning Technical Drawing, this is because of the low level of spatial ability in engineering and that's why we feel the need for creating tools and methodologies to improve that ability.

Augmented Reality (AR) technology emerges as a nice resource for the younger population which is accomplished to the latest developments in technology and entertainment. Looking forward to introducing new tools and technologies we thought of developing an approaching course based on Augmented Reality. Having in mind that an unusual tool on the teaching field is being used we must analyze several technical aspects of usability like its interface, physical problems as well as any hardware and software trouble. We check on interaction between user and augmented environment including navigation, spatial orientation, presence and immersion. About the user's engagement, we evaluate likes and dislikes as well as confidence in the mixed environment. The cognitive aspect identifies any improvement of the subject's internal concepts through this learning experience. Finally, the pedagogical aspect concerns the teaching approach: how to effectively gain knowledge about the environment and the concepts that are being taught.

In this paper, we present the results of research and comparison of specific training's effectiveness for improving the spatial skills on engineering students from two Spanish universities. The training proposed is voluntary for students from mechanical engineering of both universities. Although it's important pointing out that all students have the chance to improve their spatial skills as this is an autonomous training which students can perform anytime as material is available for everybody. Our specific aim is checking out that training is efficient and enough in both universities for stating differences between levels reached. Our broad aim is incorporating this training in engineering degrees curriculum to provide reinforcement of skills during a student's undergraduate career.

This paper is organized as follows: a brief overview of the literature on spatial skills is provided. The training system description based on augmented reality is followed by description of experimental tests and finally, the results and conclusions.

SPATIAL ABILITY: AN OVERVIEW IN ENGENEERING

Cognitive psychology researchers have published their theories about spatial skills concept and it's usual to find terms from different authors referring to the same concept or the same term referring to different concepts. According to different authors, intelligence is composed by several factors, components, skills or abilities: verbal, numeric, spatial, memory, reasoning, etc. Their number varies according to each author, but all of them agree that one factor of intelligence is the spatial skill which is composed by several sub-components: spatial relations, spatial visualization, mental rotation, perception, etc.

Sánchez Carlessi and Reyes Romero [7] define the term 'skill' as the ability owned by the individual allowing him to act and perceive going beyond natural laws. They consider that someone is ready to do something because he owns a certain attitude, skill and ability to develop it. Going into specifics (which may extend to the rest of skills), it's pointed out that attitude is an inborn aptitude or natural strength owned by the individual meanwhile dexterity is the ability developed by a person with a high efficient level and skill comprises solving mental spatial tasks thanks to training, exercises and experience (Figure 1). Starting from an initial potential we can train and develop this skill.

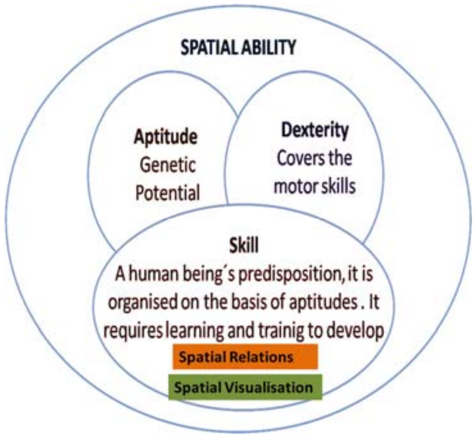


Figure 1. STRUCTURE SPATIAL ABILITY.

Sorby [8] discusses the difference between "spatial abilities" and "spatial skills." Technically, the former refers to innate abilities and the latter to learnt abilities; however, both terms are often used alike.

"Spatial skills" refers to a collection of cognitive, perceptual, and visualization skills. While lists may differ, there is substantial agreement that the core spatial skills are [9]:

- the ability to visualize mental rotation of objects
- the ability to understand how objects appear in different positions
- the ability to conceptualize how objects relate to each other in space
- three-dimensional (3D) understanding

Some of the most accepted theories come from researchers [10, 11] who have proposed three major sub-factors for categorizing spatial skills: spatial relations, spatial visualization, and spatial orientation, although some researchers don't recognize spatial orientation as a separate factor. The following classification proposed by researchers on both psychology [12] and engineering fields [13], are now reduced to just two sub-factors:

- *Spatial relations*, defined as the ability for imagining rotations in both two and three dimensions. Authors indicate that this skill includes mental rotation and spatial perception factors.
- *Spatial visualization* which is the ability to recognize 3D objects through the folding and unfolding of their faces. Visualization is defined as the ability of mental management of complex shapes.

To measure these components we use both the Mental Rotation Test (MRT) [14] and the Differential Aptitude test (DAT-5: SR) [15], as they are highly valuable tools for performing measurements of spatial skills (Figure 2).

Research on factors that affect the development and exercise of spatial skills has traditionally focused on gender differences in performance. An investigation subject is the link between spatial skills and gender as women usually have lower levels of these skills which have an influence on their access to engineering degrees such as civil, electrical, mechanical or computer engineering. Several reports point out that actually barely 10% of all engineers on duty and less than 20% engineering students are women [16, 17]. In Gibbon's study showed that only 8.5% of women got a university degree in any engineering [18].

Recent research, indicates that other factors, such as socioeconomic status and working memory capacity, may be involved. Research identifying these other factors affecting skill levels further indicates that an underlying factor may be the level of access to and use of objects and activities shown to improve spatial abilities such as video games [19, 20]: activities which males are more likely to use than females.

Sorby [21] mentions that pre-college participation in activities relying on hand-eye coordination tends to be high among postsecondary students with good to excellent spatial skills, including certain sports and technical education/industrial arts classes.

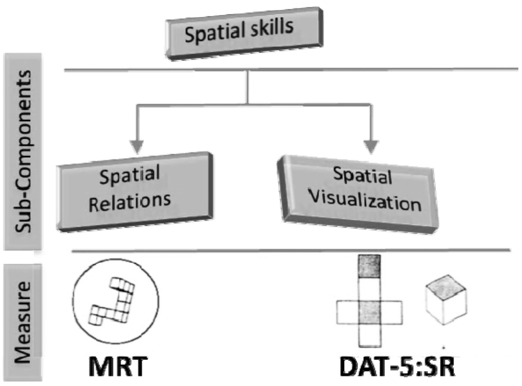


Figure 2. FACTORS AND MEASUREMENT TEST FOR SPATIAL SKILLS

Some studies in the engineering field demonstrate that spatial abilities can be improved by means of specific training with multimedia exercises, video games, 3D software and other technologies used in graphic engineering [3, 5, 8, 22]. According to Mohler [23], spatial ability is the most important out of all the other abilities an individual can possess, which will enable them to carry out all kinds of tasks related to the engineering profession.

In the area of engineering, specifically in technical design and representation of views, there is an obvious connection with spatial reasoning and geometric transformations; both are excellent catalysts for developing perceptive abilities of students [24]. The integration of various orthographic views from the perspective of a student produces a training of spatial visualization, and obtains new orthographic views from the given view. This is a way which helps to understand the spatial relationship. Training of spatial visualization is achieved (among other exercises), proposing the student the choice of the appropriate model, which is reached through a process of mental manipulation from input data. In general, the procedures are the folding and unfolding of object surfaces. The spatial relationship is developed by recognizing a three dimensional object from different angles, which requires the student to recognize spatial position and relation to other objects. Sorby, et al. [2] is one of many reports about how instruction in 3D CAD modeling leads to increased scores on tests of spatial reasoning skills. However, interventions do not necessarily need to be computer-based to be effective; technical drawing, 3D modeling with craft materials, and drafting activities have been shown to help develop and improve spatial skills; see, for example, [3, 13]. These studies serve as a reminder that effective interventions can also be low-cost and accessible, an important point to practitioners operating in resource challenged environments.

AUGMENTED REALITY APPLICATION FOR TRAINING SPATIAL ABILITY

A software library called HumanAR have been developed in order to ensure the integration of Augmented Reality into our applications and to overcome some drawbacks present in some public libraries.

The version of HumanAR shown here has been specially tuned to ensure a reliable implementation of the augmented book used in this experiment. This library uses computer vision techniques to calculate the real camera viewpoint relative to a real world marker, that it calculates the integration of three-dimensional objects codified by the camera and captured by the camera in real time. When the marker enters the scene picked up by the camera, the fusion of the real world with the virtual object is shown on the screen. This requires the application to relate the two worlds (real and virtual) in a single system of co-ordinates.

To improve spatial ability on students, we have created a toolkit that promotes active learning, and encourages discovery through interactivity and object manipulation controlled by the learner. The AR toolkit is composed by: a software application, an explanatory video and the augmented book.

- The software application contains the three dimensional virtual models. These models will be visualized on the computer screen when fiducial markers are received by the webcam.
- The short explanatory video explains the theoretical contents of orthographic views and freehand sketching.
- The augmented book provides fiducial markers of virtual three dimensional objects and contains exercises to be solved by the students.

Each page of the book contains an activity and a pair of fiducial markers identifying the exercise and the 3D model linked. Besides, there is a general marker used for visualizing the piece belonging to each exercise (see figure 3).

Figure 3. USING AR APP AND AUGMENTED BOOK

The way of interacting with the augmented book is showing to the screen the fiducial markers from the book so the exercise's number appears on screen. Also, the user can visualize the 3D object it from any point of view.

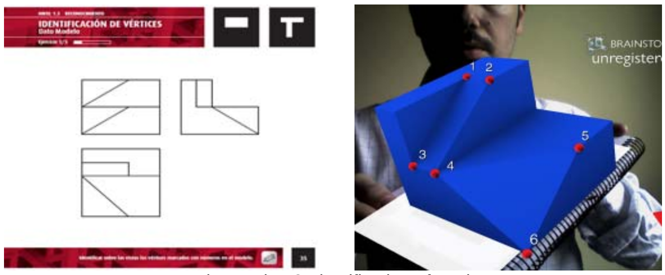
The first exercise of each level is a solving example, so they have a linked interactive gesture for visualizing the solution. Like in the rest of the exercise, the user may visualize the 3D object through the general marker, although if he performs the gesture of bringing the object nearer to the camera, the exercise's solution will be shown on screen.

Several researchers [26] report that learners who have active control over novel objects perform better on later tests of object recognition and mental rotation. Further evidence suggests that active exploration and control of novel objects assists the learning of 3D structures, better object recognition and improved spatial ability. The content proposed in the augmented book is an effective way of improving spatial abilities due to mental visual operations students have to carry out. This set of activities contributes to the development of the spatial factor of the intelligence. The didactic material was created using Bloom taxonomy [27] being structured on levels *(knowledge, comprehension, application, analysis-synthesis, and evaluation)*, each one containing several kinds of exercises.

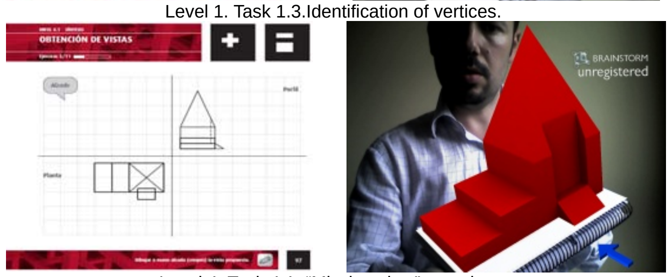
Purpose training is structured into five levels with duration of two hours for each one, excepting level 5 (evaluation) where six exercises must be completed in just one hour without any model help. The training is organized into five sessions with a total duration of nine hours (four sessions of two hours and a final session that lasted one hour). Students can visualize the three-dimensional model in augmented reality and they can check if their freehand sketches correspond to the three-dimensional virtual models which they are viewing.

- *Level 1 (Knowledge).* The students have to identify surfaces and vertices on both orthographic and axonometric views of a three-dimensional virtual object, which is created on the augmented book (contain three kinds of tasks).
- *Level 2 (Comprehension).* The students have to identify orthographic views of the virtual three dimensional models from the exercise book (contain two kinds of tasks).
- *Level 3 (Application – Analysis).* It is devoted to the identification of the spatial relationship between objects. This is carried out by means of "recount" exercises, where students are asked to identify how many objects are in touch with one selected. Also there are exercises about the selection of the minimum number of views to completely define an object (contain two kinds of tasks).
- *Level 4 (Synthesis)* Its difficulty is greater than previous levels. There are exercises where the students have to sketch a missing orthographic view, knowing two orthographic views of a model, using the virtual model as the only input, they have to sketch all the orthographic views (contain two kinds of tasks).
- *Level 5 (Evaluation).* The exercises are the most difficult ones for students, because they require a greater level of spatial ability. Students are provided with three orthographic views of each object, and they have to build in their minds the corresponding three-dimensional model and then draw a freehand perspective of it. Students have one hour to complete six exercises, without any virtual model help. This level of the course is used for evaluating the advance of students.

When they have carried out the proposed isometric drawings, they can be verified.



Level 1. Task 1.3.Identification of vertices.



Level 4. Task 4.1. "Missing view" exercises.

Figure 4. EXAMPLES OF SEVERAL KINDS TASKS

This training is available for everybody through the www.ar-books.com website where the augmented book can be obtained and the AR application is available for download.

To promote students' autonomy, a Youtube tutorial for each type of exercise has been developed. This allows greater freedom for each student to advance at his own pace.

http://www.youtube.com/user/AugmentedRealityBook

METHOD

Study´s description

The participants from this study were engineering students from both universities at the Canary Islands (Spain). Those first's year mechanical engineering students performed the training for improving their spatial skill through AR. Therefore, 41 students from the Las Palmas de Gran Canaria University and 25 from La Laguna University took part on it. Besides, we chose a control group of 25 students who were randomly selected from the same degree and course than those performing this training. The participants belonging to the control group belong to both universities (12 from La Laguna and 13 from Las Palmas) didn't perform any kind of previous training.

Training was done at home on their own. The target is obtaining results about spatial ability's improvement in the groups belonging to both universities so they can be compared.

The study was performed during the first week of the academic year 2011/12 around October so, at the time of taking part in the experience, these students had not attended any Engineering Graphics classes in their degree courses. Spatial abilities of engineering students were measured before and after training through both Mental Rotation Test (MRT) and Differential Aptitude Test (DAT-5:SR).

For undertaking the training, only a standard PC and webcam are required. Students will visualize virtual elements on the monitor. It's intended that students carry out training five times in sessions on their own at home as no teacher assistance is needed. In the first briefing with the students, they were updated on the purpose and need for undertaking the training as well as obligation of submitting back to the teacher the training's notebook with all solved exercises when it's finished as guarantee that they have completed it. Later tests will be run to measure spatial skills and supplying the toolkit (augmented book and website where AR app is available for download). Afterwards instructions are explained on how to carry out training: "five levels, which will be completed in five consecutive days". It is considered that two hours work is required for each level with the exception of the fifth which requires just one hour. Once training is finished, students hand the completed exercise book to the teacher whilst spatial ability levels are measured once again for comparison with pre-training levels.

Measures and results

In Table 1, MRT (spatial relations) and DAT-5:SR (spatial visualization) values can be found before and after training for the three groups: general, experimental and control group. Mean values prior to training are quite similar in all three groups.

The analysis of variance (ANOVA) for MRT and DAT-5:SR measured in the three groups (general group, experimental group and control group), showed there were no significant differences between groups prior to spatial training ($F_{2,90}$=1.817, p=0.169 on MRT and $F_{2,90}$=0.264, p=0.769 on DAT-5:SR). So, all groups were statistically equivalent in spatial visualization and spatial relation at the outset of this study.

Table 1. VALUES PRE/POST TEST AND GAIN SCORES

	Pre- test MRT	Pre- test DAT 5:SR	Post- Test MRT	Post- Test DAT 5:SR	Gain MRT	Gain DAT 5:SR
Las Palmas Group n=41	15.88 (6.05)	27.54 (8.85)	25.07 (7.54)	37.41 (8.10)	8.04 (5.31)	9.29 (4.08)
La Laguna Group n = 25	19.67 (7.90)	29.17 (7.28)	27.70 (7.82)	38.46 (7.04)	9.19 (6.69)	9.87 (5.03)
Control Group n=25	17.44 (9.82)	28.40 (10.17)	22.08 (9.94)	33.52 (11.77)	4.64 (4.36)	5.12 (7.13)

We compared the mean values obtained in pre and post tests using the *t-Student paired series test:* the training Las Palmas group scores show t=8.80 for the MRT; p-value=0.0 and DAT-5:SR t=12.57; p-value=0.00; the La Laguna group scores t=7.42 for the MRT, p-value=0.00 and DAT-5:SR t=11.15; p-value=0.00. In the MRT test, the control group obtained t=5.32; p-value=0.00 and in the DAT-5:SR t=3.59; p-value=0.001.

The groups that underwent training showed a statistical improvement in spatial ability levels. P-values are around 5% of statistical significance, which indicates that the students have a probability of over 95% of improving their levels of spatial ability by training as proposed by Augmented Reality. Besides this, results show there is no improvement in control group levels. To compare and check if there is any difference between spatial ability levels obtained by groups that underwent training, a contrast analysis post-hoc LSD Fisher is performed. This allows multiple comparisons between the three groups with a different number of individuals in each group as seen on results Table 2 and Table 3.

The results confirm that there is a significant difference between each one of the training and control groups but there is no difference between the training groups which underlines that improvement gained by the students has been similar on both universities.

Table 2. COMPARISON BETWEEN GROUPS FOR GAIN MRT

(I) group	(J) group	Difference between averages (I-J)	Typical error	Sig.	Confidence interval at 95%	
		Lower limit	Upper limit	Lower limit	Upper limit	Lower limit
1	2	1.15346	1.4826	.439	-1.7935	4.1004
	3	4.55512(*)	1.4638	.003	1.6456	7.4646
2	1	-1.15346	1.4826	.439	-4.1004	1.7935
	3	3.40167(*)	1.6485	.042	.1250	6.6783
3	1	-4.55512(*)	1.4638	.003	-7.4646	-1.6456
	2	-3.40167(*)	1.6485	.042	-6.6783	-.1250

1 (La Laguna Group), 2 (Las Palmas Group), 3 (Control Group)

* Difference between averages is significant at .05 level.

Table 3. COMPARISON BETWEEN GROUPS FOR GAIN DAT5:SR.

(I) group	(J) group	Difference between averages (I-J)	Typical error	Sig.	Confidence interval at 95%	
		Lower limit	Upper limit	Lower limit	Upper limit	Lower limit
1	2	.58638	1.4093	.678	-2.2148	3.3876
	3	4.75805(*)	1.3914	.001	1.9924	7.5237
2	1	-.58638	1.4093	.678	-3.3876	2.2148
	3	4.17167(*)	1.5670	.009	1.0570	7.2863
3	1	-4.75805(*)	1.3914	.001	-7.5237	-1.9924
	2	-4.17167(*)	1.5670	.009	-7.2863	-1.0570

1 (La Laguna Group), 2 (Las Palmas Group), 3 (Control Group)

* Difference between averages is significant at .05 level.

CONCLUSION

Augmented reality is a cost-effective technology to provide students with attractive contents with respect to paper books, giving new life to classical paper and pencil exercises. In educational applications, it is of utmost importance to focus students´ attention on the actual task and to reduce the cognitive overhead needed to use the application. This motivated us to design a user-friendly system and a friendly and agreeable environment. This AR application has proven to be an efficient and effective material for developing spatial abilities and for learning engineering graphics contents. The software has proven to be robust as no errors have shown up during its use.

According to results, the students accessing both mechanical engineering at canary universities don’t show significant difference respecting spatial skills levels. Students from both universities improve their spatial skills in the same way obtaining better results than the average value belonging to the whole country.

For engineering students, having a good level of spatial skill helps them getting a better performance in academic tasks, and training like the one proposed on this paper may provide them with the proper level of spatial skill

Following the trend pointed by The New Media Consortium's 2011 in Horizon Report [28], I regard augmented technology will be used in university didactic material in the short-term because students use electronic gadgets (smartphone, iPads, laptops, etc.) frequently while studying and looking for information.

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