Development of an Augmented Reality Based Remedial Course to Improve the Spatial Ability of Engineering Students

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Abstract—**This paper presents the results of a pilot study designed to evaluate the effect of attending an intensive remedial course (8 hours worth of work during one week) based on desktop augmented reality exercises to improve the spatial ability of freshman engineering students. Activities based on practice with an augmented reality enhanced exercise book had a positive effect on students' spatial ability, measured by both MRT and DAT:SR tests. To promote students' autonomy, a YouTube tutorial for each type of exercise was developed. This allowed greater freedom for students to advance at their own pace during the training sessions. An evaluation and satisfaction questionnaire based on a five level Likert scale was submitted by participants. The experience was considered very positive by students.**

Augmented reality; spatial skills; remedial course (key words)

I. Introduction

Spatial ability is a key element to students' success in science, technology, engineering, and mathematics (STEM) disciplines [1],[3]. Although some students are better at spatial thinking than others, everyone can improve with appropriate training. Development of students' spatial thinking is currently not widely covered by the educational system, although there are many studies that justify that spatial ability plays a critical role in developing expertise in STEM [2]. Spatial skills are usually developed indirectly. Onyancha & Kinsey report that those students in engineering majors which rely more heavily on these skills (e.g. mechanical engineering) increase them more than other engineering majors [6] from freshman to senior years due to their exposure to an engineering curriculum.

In the context of the Spanish educational system, many students enroll in engineering undergraduate degree programs without proper spatial skills. This paper presents the results of a pilot study designed to evaluate the effect of attending an intensive remedial course based on desktop augmented reality exercises to improve 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. Due to this fact, the School of Industrial Engineering at Universitat Politècnica de València (UPV) in Spain provides a series of remedial courses at the beginning of each academic semester to give support to those students that need extra help to follow the regular courses. However, in recent years, some of these remedial courses have been suffering a growing lack of interest and motivation in students. This was the case of the "Introduction to Graphical Expression" remedial course based on classical paper and pencil exercises. The growing gap between the teaching procedures and the technological way of life of students [7] requires bringing new resources to the teaching/learning process. Besides, true learning is experiential. The more senses that are involved (sound, sight, touch, emotions, etc.), the more powerful the learning experience is [8]. In this context, augmented reality (AR) can play an important role supporting experiential learning and giving the students an appealing technological tool to support their learning activity. This has been the approach followed to improve the remedial course "Introduction to Graphical Expression".

In the next section, previous experiences using AR for spatial skills improvement are analyzed. Then the didactic contents used for the development of the remedial course are presented, with all the details about the experimental design. Section IV reflects the results obtained. Discussion and conclusions are presented in the last section of the paper.

II. Related Work

Although spatial ability has been studied using Virtual Reality technology [10],[13] there is a very small number of studies about the application of AR to train spatial ability. In 2006 Dünser et al. [9] presented the first large-scale study (215 students) that analyzed whether spatial ability can be trained using an AR application. They used their collaborative augmented reality system Construct3D. This system employed see-through head-mounted displays (HMD) for the visualization of three dimensional objects that students usually calculate and construct with paper and pen methods. Training groups were composed of two students and a tutor, that attended six 45 minute training sessions (once a week).

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Participants worked on the post-test 10 weeks after completing the pre-test. The training was centered on the use of combinations of Boolean operations and transformations in space to model objects. This study could not find a clear advantage for AR-based geometry training in improving spatial ability.

Do & Lee [12] developed a desktop augmented reality 3D LEGO game as a tool to develop spatial ability. The game allows practicing different spatial skills such as analyzing a 3D model's structure, figuring out what to do to make a primitive geometry become a component of a 3D model and assembling components to create a complex model. Physical markers are used by players to control the game. The main limitation of this study is that the authors did not employ any spatial ability test to verify the effect of playing the AR game on players' skills. They concluded that the 3D LEGO game improved players' skills using a questionnaire where users evaluated the game. One of the questions was if the user considered that the game was able to improve spatial abilities. This question received an average score of 6.8 out of 7 from the 67 participants.

Chen et al. [14] developed two teaching aids for the explanation of the relationship between three-dimensional (3D) objects and their projections. These aids where tangible models (physical objects) comprised of a set of differently shaped pieces and augmented reality models. The authors conducted a user test on 35 engineering-major students. However, they did not apply any standardized spatial ability tests to measure the impact of their intervention on participants' skills. They concluded that tangible models significantly increased the learning performance of students in their abilities to transfer 3D objects onto two-dimensional (2D) projections. Students also demonstrated higher engagement with the AR models during the learning process, although the augmented reality model had little effect on the capability for the transformation of 2D images into 3D objects.

III. Materials and Methods

The "Introduction to Graphical Expression" remedial course is short and intensive (16 hours of work, during 2 weeks) and it is offered as an elective course to those students enrolled in the first-year "Graphical Expression" course with a poor technical drawing background. Its general learning objectives are to promote the learning of the systems of representation and the knowledge of the common geometric shapes used in engineering. The course is arranged in two blocks.

The first block (four 2-hour sessions in a week) is based on classical paper and pencil exercises where a basic review of metric geometry, the foundations of graphical representation and multiview and axonometric representation systems are provided to participant students. In this part, students are provided with wooden models to support the execution of some exercises.

The second block (four 2-hour sessions in a week) is based on an augmented reality application that uses virtual 3D models to help students to realize a series of activities designed to exercise their spatial skills. Each student is provided with an "augmented book" [17]. There is an exercise in each book's page that is coded using a couple of small fiducial marks embedded in the book layout. The student uses another fiducial mark (printed on cardboard o loaded in their mobile phone, as seen in Fig. 1) to manipulate and interact with the virtual model linked to that specific exercise.

To promote students' autonomy, a YouTube tutorial [18] for each type of exercise has been developed. This allows greater freedom for each student to advance at their own pace, as to advance, they do not need to wait for the teachers explanation or to adapt to the speed of the rest of the class. This option has been positively valued by the participating students.

A. *Description of augmented reality contents*

The second block of the remedial course is based on the resolution of a series of exercises organized in level of increasing difficulty.

Level I exercises require the identification on the projected views of the surfaces marked on the AR model (Fig. 1 & 2).

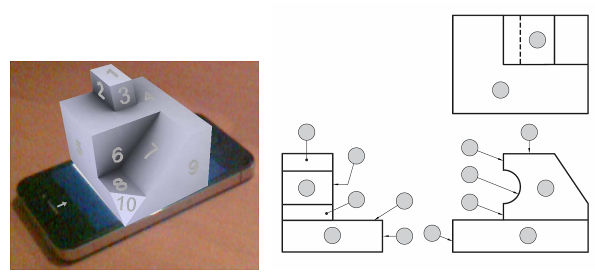

Figure 1. Using a mobile phone to manipulate the fiducial marker.

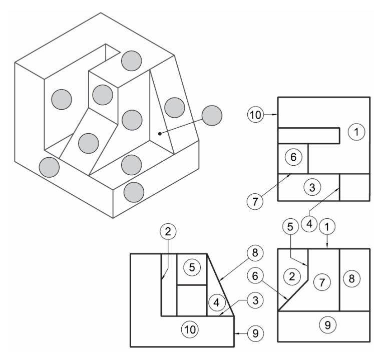

Figure 2. Write in the perspective view the number that corresponds to the surfaces marked on each view

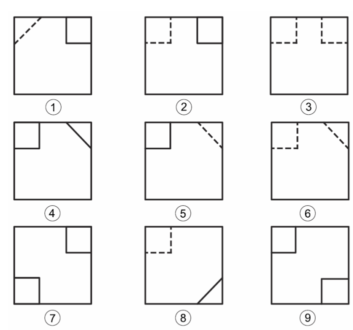

Figure 3. Identify the views that correspond to the virtual object

The second level consists of a series of exercises where students have to select the correct projection view for the representation of a virtual model manipulated through the AR application (See Fig. 3 for an example).

The third level is devoted to prism identification exercises (Fig. 4), and the election of the minimum number of views for the representation of a virtual object (Fig. 5). The fourth level consists of an initial set of exercises where the students have to solve missing view problems (Fig. 6) and draw the normalized views of a virtual objet.

The last level does not employ a virtual object. The input for students is a set of views, and they have to sketch a perspective drawing of the corresponding part.

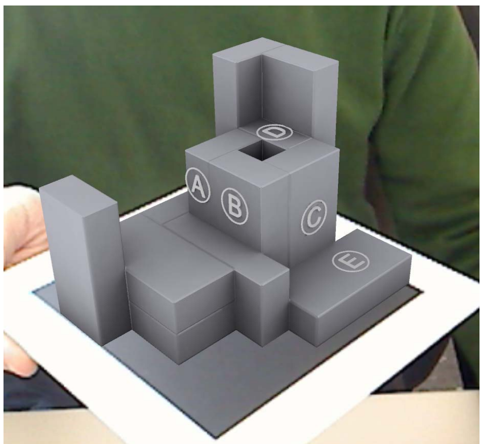

Figure 4. Prism identification exercises.

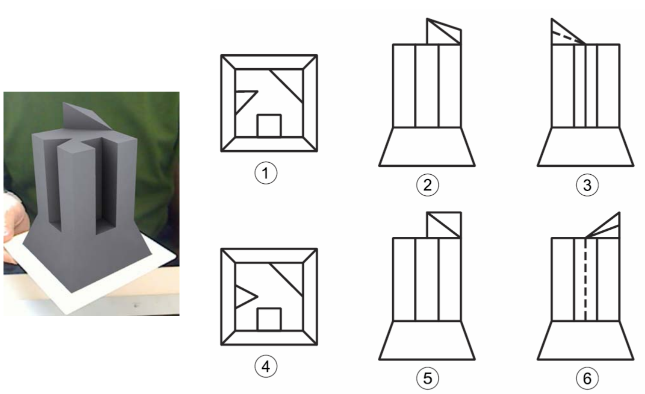

Figure 5. Minimum views exercises

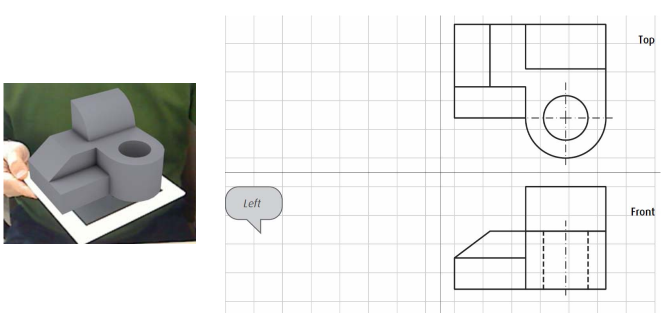

Figure 6. Missing view exercises

B. *Participants*

This remedial course was offered to freshman engineering students that were enrolled in the “Graphical Expression” course of the Bachelor's Degree in Industrial Technologies Engineering offered by the School of Industrial Engineering from UPV. 27 students participated in this elective course during the first two weeks of February 2012 and formed the experimental group. A control group of 15 students was selected from one of the regular groups of the “Graphical Expression” course. The control group does not perform any activity related to spatial skills training during the period of realization of the remedial course.

C. *Instruments*

Although spatial ability is a complex topic, where several subcomponents are identified, for this work only two categories have been considered, firstly “spatial relations” related to tasks that require the mental rotation of simple two-dimensional or three-dimensional objects. Secondly “spatial visualization” that requires the mental manipulation and integration of stimuli consisting of more than one part or movable parts, where usually there is movement among the internal parts of a complex configuration and/or the folding and unfolding of flat patterns. Two tests have been chosen to quantify the values of the spatial ability of participants:

- Mental Rotation Test (MRT) [3] (20 items) for the “spatial relation” subcomponent.
- Differential Aptitude Test (DAT-5:SR level 2) [5] (50 items) for the “spatial visualization” component.

Both experimental and control groups were pre-tested the week before starting the augmented reality based training (second block of the remedial course). Both groups were post-tested the week after they ended the training.

IV. RESULTS

In Table I, MRT (spatial relations) and DAT-5:SR (spatial visualization) values can be found before and after training for both experimental and control groups. As a null hypothesis H_0, it is considered a fact that there is no statistical difference between average values of both groups. The result of comparing both average values using a “*t*-student in independent series” analysis shows there were no significant differences between groups prior to spatial training, so the null hypothesis H_0 is rejected ($t = -1.557$, p-value $= 0.127$ on DAT-5:SR and $t = -1.836$, p-value $= 0.073$ on MRT). In this case p-values are over 5%, so both groups were statistically equivalent in spatial visualization and spatial relation at the outset of this study.

TABLE I. MEAN AND (STD. DEV.) SCORES FOR PRE & POST TESTS

	Pre- test		**Post- Test**		**Gain**	**Gain**
	MRT	**DAT**	**MRT**	**DAT**	**MRT**	**DAT**
Experimental Group n = 27	17,04 (6,66)	34,66 (9,42)	25,81 (7,83)	41,11 (7,71)	8,77 (5,54)	6,44 (5,44)
Control Group n=15	21,4 (8,55)	39,26 (8,68)	28,26 (10,56)	41,26 (7,77)	6,86 (5,75)	2,00 (5,01)

In Table II results corresponding to the comparison of the mean scores obtained in pre and post tests using the t-Student paired series test are shown.

TABLE II. RESULTS OF COMPARISON OF AVERAGE SCORES

Training Group	**PreMRT vs Post MRT**	t = -4.435	*p*-value = 0.00
	PreDAT vs Post DAT	t = -2.749	*p*-value = 0.008
Control Group	**PreMRT vs Post MRT**	t = -1.957	*p*-value = 0.06
	PreDAT vs Post DAT	t = -0.664	*p*-value = 0.511

The group that underwent training shows a statistical improvement in spatial ability levels, where *p*-values are below 1% of statistical significance, which indicates that the students have a probability of over 99% 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.

TABLE III. QUESTIONNAIRE. MEAN SCORE AND (SDT. DEV.)

Q1: The course contents look good.	4.4 (0.84)
Q2: The manipulation of the virtual model with the cardboard marker is adequate.	4.1 (0.73)
Q3: Course levels are well organized and the difficulty and characteristics of exercises are adequate.	4.1 (0.85)
Q4: YouTube videos are a good help to resolve doubts.	3.3 (1.03)
Q5: The augmented reality application worked well.	4.1 (0.92)
Q6: Image quality is good. Virtual objects do not present jittering.	3.2 (0.95)
Q7: The number of exercises to be solved is adequate for the available time.	4.6 (0.78)
Q8: I feel confident to solve all the proposed exercises.	4.6 (0.90)
Q9: The number of exercises of each work session was correct.	4.7 (0.78)
Q10: The manipulation of the virtual object with the cardboard mark is easy to learn	4.6 (0.59)
Q11: The concept of the augmented book is intuitive and easy to understand.	4.6 (0.66)
Q12: I think that the course has improved my spatial skills.	4.3 (0.88)
Q13: I think augmented reality technology is very interesting	4.7 (0.47)
Q14: I think augmented reality technology is very original	4.5 (0.67)
Q14: I think augmented reality technology is very useful	4.3 (0.83)
Q15: I think augmented reality technology is very stimulating	4.1 (0.87)
Q16: I would like to use augmented reality during the regular "Graphic Expression" course.	4.7 (0.71)
Q17: I would prefer to do these kinds of exercises only with paper and pencil	2.4 (1.38)
Q18: I think that the manipulation of the virtual model with the cardboard marker is easier than using the mouse.	4.1 (1.10)

V. DISCUSSION AND CONCLUSIONS

The results obtained agree with the previous experience of our research group [15],[16] that augmented reality based training for the development of spatial skills is a feasible approach that provides good results and offers an attractive stimulus to students to enroll in elective activities.

Low cost desktop augmented reality is very easy to implement, adding a webcam and the proper software to a regular CAD computer lab. Although the augmented reality contents presented here are relatively simple, only requiring one mark manipulation, student preferred this physical interaction to the typical mouse interaction (as can be seen in Table III, Q18). This confirms past research into the application of spatial ability in engineering education that suggested that motor activity contributes to the comprehension of the concept of space [19]

The concept of the augmented reality book was very well considered by participant students, as Q11 shows. The book layout has been designed to support a seamless integration of fiducial markers in the page layout, in such a way that they do not distract or break the point of interest centered on each exercise. Students receive the virtual content on a specific cardboard marker that they can manipulate independently of the exercise book. This tangible interaction probably gives the real added value to the experience as Q2, Q5, Q10 reflect.

Perhaps problems will appear when, in the future, students ask for more augmented reality contents to support the regular "Graphic Expression" course. The wide adoption of augmented reality requires authoring environments oriented to provide support to the teacher with a creative and active attitude towards the new technologies. However, current authoring tools are programmer oriented, and require a big effort to create the didactic contents.

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