Application of Augmented Reality for teaching Descriptive Geometry and Engineering Graphics Course to First-Year Students

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Abstract

The quality of modern engineering education is directly linked with the students' ability to create and read the drawings of engineering structures. The subject "Descriptive Geometry and Engineering Graphics" taught in the undergraduate engineering studies develops students' ability to analyse both the shape and design of real objects and, along with the spatial reasoning, the technical thinking. The development of spatial skills for engineering students is closely related with the success in their future professional career. The new information technologies (IT) offer novel opportunities to enhance the classic teaching approach used so far during mastering quite complicate and extensive courses, like engineering graphics. Augmented Reality (AR) is one of the many challenges of modern IT technologies which recently became available also for education purposes. It is supposed that AR will provide new possibilities to teach the contemporary generation of students in an attractive and more entertaining way. First part of the article describes the results of the application of didactic toolkit AR-DEHAES based on Augmented Reality for development of spatial ability of students. In the second part of the article presented are the examples of 3D objects for the exercises of "Descriptive Geometry and Engineering Graphics" course prepared for the use into AR environment. The use of AR technology facilitates the students to acquire better practical skills in much shorter time during their academic studies and improves the quality of graphic education.

Keywords: *Augmented Reality, Engineering Education, Spatial Skills, Descriptive Geometry*.

1. Introduction

Current advances in information and communication technologies (ICT) have enhanced the need to incorporate these achievements into education process. Many researchers assume that nowadays students, digital natives, are common users of ICT. [1] These technologies are attractive for them, and can improve their self-education process. The educators try to exploit the entertaining features of ICT in education and to investigate how the application of those technologies effects on students ability of three-dimensional visualisation and free manipulation of geometrical shapes. At the same time, the investigators want to find out whether advanced technologies could help from the beginning of the student's academic learning, to improve their performance in the spatial comprehension process and graphic representation skills. [2] [3]

In this way the Augmented Reality (AR) technology is used, because the user-machine interaction much faster enhances spatial coordination, observation and manipulation of the virtual objects. Augmented Reality can be defined as an integration of virtual elements into the real environment. AR technology appears as a good resource for the younger population which is accomplished to the latest developments in technology and entertainment. [4] This technology is easy to use and needs a very basic computer training to be visualised, forcing the student to develop the ability of reading and representing geometric shapes, which could be useful for future professionals. Complex and expensive systems were avoided in this research demonstrating that ICT tools for development of spatial ability can also be low-cost and accessible to a wide range of users.

Currently in RTU there is a shortage of lecture hours in the engineering curricula for the subjects related to engineering graphics that lead to a decrease in the amount of time explaining theoretical and practical content. The presentation of some topics is performed in very condensed form. This situation adversely effects on the development of spatial and graphic representation skills of students. It should be recognized that undergraduate students meet difficulties in the study of the subject “Descriptive Geometry and Engineering Graphics” and therefore there is a need for creating of new attractive methodologies of teaching.
In this paper reported is the experience in the design and evaluation of new didactic method, in order to help the students to improve their spatial and graphic skills. In this educational research investigation, the goal is to evaluate the effectiveness of the use of AR in learning processes of engineering undergraduate students.

In first section of this study the use of didactic toolkit AR-DEHAES in teaching of undergraduate students of RTU is described. This toolkit is based on AR which has been developed at the University of La Laguna in Spain. [4] The teachers of University of La Laguna consider AR as technology which offers tools for creation of attractive teaching content and development of spatial skills. The second section describes the preparation of 3D objects from conventional graphic exercises from the course “Descriptive Geometry and Engineering Graphics” and transformation to AR environment. The final section presents the conclusions gained from the experience.

2. Spatial ability and AR training

For the AR training just one standard personal computer and a webcam are required. Student will visualize virtual elements on the monitor. The AR-DEHAES toolkit consists from a software application and an augmented book. [5] This book contains questions and exercises to be solved by the students and provides fiducial markers of virtual 3D objects. The marker-based method was used in present study and it consists from a black square with special symbols inside. This marker, which is associated with a particular graphic exercise, allows recognizing the virtual objects. The application requires an accurate position and orientation tracking of the marker in order to register the virtual element in the real world. When the main marker is picked up by the camera, the integration of the real world with the 3D virtual model is generated on the screen. Students can visualize the 3D model in AR and they can check if their freehand sketches match the 3D virtual models which they are observing. The students perform AR-DEHAES training autonomously. In the first briefing the students receive information on the principles of using the software and terms of submission of solved exercises.

The experimental group of 48 freshman students (33 females and 15 males) working on an engineering degree at the RTU participated in this study using AR-DEHAES toolkit. The majority of students were between 19 to 21 years of age. Only two percent of them had studied the subjects related to engineering graphics before at the secondary school. All the students were full-time students and many of them considered themselves to have difficulties with spatial abilities or perception. The concept of study was that if the students will complete exercises with didactic toolkit AR-DEHAES it will improve their spatial abilities and will help them in better understanding the classic topics of engineering graphics. To check the effectiveness of such training a control group of 24 first year mechanical engineering students was used. This group studied the same subject but exclusively in a traditional way which included only manual sketching, orthographic and isometric projections, sectioning and dimensioning, detail drawings, etc. At the beginning and at the end of the course both groups of students completed tests for evaluation of their spatial skills.

There are many spatial aptitude tests which contain instruments to evaluate the level of ability of space visualization of a person. Most of them are composed of perspective figures showing rotated objects that an individual, through its ability to make mental rotations and comparisons, must recognize in order to tell if it is or is not the same object as a supplied reference.

The most common types of spatial tests are [6]:

a) Spatial Visualization Tests which are used to assess a person's ability to mentally manipulate 2D and 3D figures,
b) Mental Rotation Tests which evaluate the ability of mind to rotate an object while identification – is it the same from any perspective, or the skills of the mind to leave the body and look at an object in another perspective without change of the head's position.

Spatial abilities of engineering students in these tests were measured before and after the training by means of Mental Rotation Test (MRT) – a Purdue Spatial Visualization Test: Rotations (PSVT: R) and Spatial Visualization Test (SVT) – a Differential Aptitude Test: Spatial Reasoning (DAT: SR). Figures 1 and 2 show the examples of actual questions from both tests.

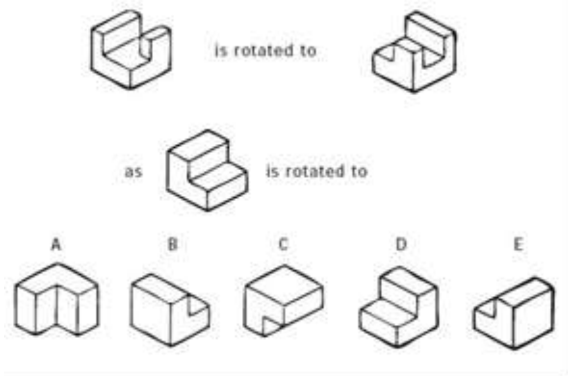

Figure 1. Example of PSVT: R test question.

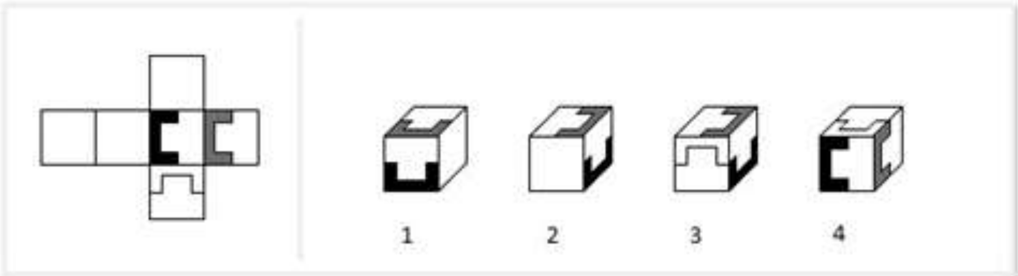

Figure 2. Example of DAT: SR test question.

For the statistical analysis a Student's t-test was used, taking as the null hypothesis (H_0) the fact that mean values for spatial abilities did not vary after the end of the course. The t-test for paired series was applied and the ρ values are $\rho = 0.00000035 < 0.000001$ for PSVT: R and $\rho = 0.0000000019 < 0.00000001$ for DAT: SR. Hence the H_0 is rejected one can conclude, with a significance level of higher than 99.9 percent, that the mean scores for group with AR training underwent a positive variation. In other words, the course with an additional use of AR-DEHAES toolkit exercises had a measurable and positive impact on the spatial skills of students, measured by spatial aptitude tests. The increase of value is 5.33 points for PSVT: R and 11.71 points for DAT: SR. However, the regular course also enhances the level of spatial skills of the student (Table 1).

Table 1. Mean pre- and post-test and gain tests scores (standard deviation) for experimental and control groups.

	PSVT: R			DAT: SR		
	Pre-test	Post-test	Gain	Pre-test	Post-test	Gain
Experimental group n=48	18.12 (5.91)	23.45 (4.05)	5.33 (4.31)	28.07 (7.21)	39.78 (8.41)	11.71 (7.56)
Control group	17.42	21.83	4.41	27.31	36.52	9.21

n=24	(5.39)	(5.08)	(4.26)	(8.56)	(9.65)	(5.33)

An analysis of variance (ANOVA) was carried out to define the effect of the course type (regular or with AR training) on PSVT: R and DAT: SR tests. The analysis shows that there was no significant differences between two groups ($F = 0.598$, $\rho = 0.442$ on PSVT: R and $F = 0.831$, $\rho = 0.485$ on DAT: SR). Both groups did not show statistically significant difference in spatial skills at the outset of this study.

It should be noted that the research on factors that affect the development and train the spatial abilities has traditionally focused on gender related differences in the performance. It was found that males perform better on tests of spatial perception and mental rotation, and men and women perform equally well on spatial visualization tests [7]-[9]. The difference in the performance results was large only for mental rotation test. In our research the experimental group had about 70% of female and 30% of male, while in the control group the proportion was almost opposite – 60% of male and 40% of female. The difference between score gains of PSVT: R test might have been more significant with approximately equal gender ratio.

The test conducted was accompanied with a questionnaire which was used to find out the usability and satisfaction of the students with the suggested AR training application. The obtained responses showed that all the students expressed a highly positive attitude to the material and content. Most of the students considered this very useful and interesting, and generally were satisfied with the technology and methodology. All the students considered that AR-DEHAES system was enjoyable to use and 82% mentioned that AR training contributed them during the completion of graphic home assignments in “Descriptive Geometry and Engineering Graphics” subject. All the students in this questionnaire convinced that they definitely would recommend this training method to their fellow students.

3. Augmented Reality technology in learning process

Developing the ability to create and read a graphic representation of complex engineering structures is essential for any individual today’s engineering student. However, in the classroom, where lecture time during the contact hours is very limited, it is hard for the instructors to clearly illustrate the relationship between the 3D geometry and 2D projections using only one kind of presentation technique. Further experiments of some researchers on the use of other modern ICT indicates that AR technology in engineering graphics training performs much better results than the use of other modern techniques available, e.g. Virtual Reality (VR) or PDF3D models. [10] Although the differences between the effectiveness of these technologies used in the development of spatial skills are small, they still are quite relevant compared to those obtained from the students belonging to the control group.

The 3D models of engineering objects from the graphic assignments to be completed in a classic way by manual drafting were prepared for the use in AR environment. [11] These models were expected to facilitate the students’ perception during the individual studies of “Descriptive Geometry and Engineering Graphics” course. The 3D Augmented Reality scenes were created using BuildAR software. The virtual 3D models were overlaid on the real world environment as observed through the computer’s web camera, making them to appear as part of the surrounding environment (Fig. 3). In present study a BuildAR marker-based tracking method was used, which means that the 3D models appear attached to physically printed markers. For each object both an individual marker and a model were created and from which the AR scene was built up. The 3D models were modelled with SolidWorks and saved as STL files for later import into AR scene.

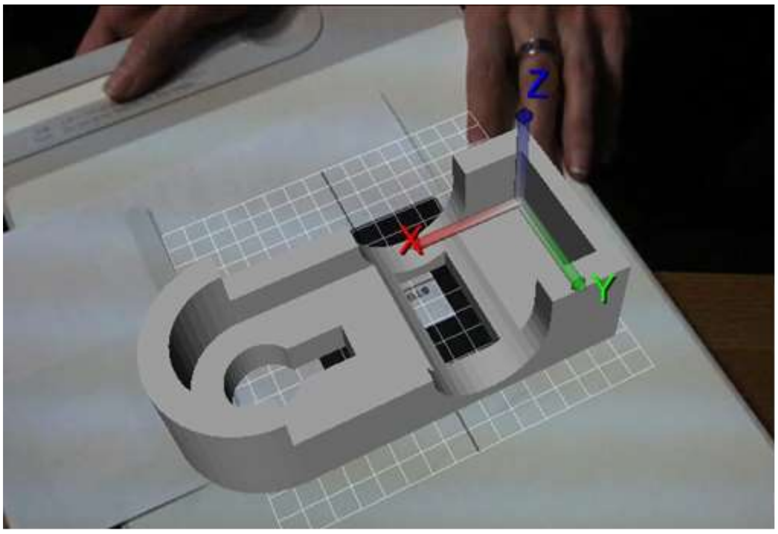

Figure 3. Three-dimensional virtual model in Augmented Reality environment.

The surveys at the end of the semester revealed the student's opinion on the effectiveness and usability of AR models in the course. All the students considered this approach as being very helpful in solving graphic exercises. It was acknowledged as very interesting and entertaining for the subjects' topics, especially on the formation of multi-view projections from isometric images or real 3D geometric objects. Very entertaining and interesting was the provided freedom of an arbitrary observation of the transformation change from 3D AR model to 2D multi-view projections, which could be easily demonstrated interactively in real time within the same one scene just in front of the computer with web camera. The overall response of the students about the use of AR model in the Descriptive Geometry and Engineering Graphics course was very positive.

Due to the advances in the development of computer technology and a simultaneous reduction in the hardware and software costs, the use of mobile Augmented Reality systems running on Smartphone may become feasible for educational institutions. As the AR application enables faster comprehension of complex spatial problems and relationships, students can greatly benefit from it during their self learning processes. Wider application of AR systems to Engineering Graphics instruction can provide the students with their own unique knowledge discovery path. [12]

4. Conclusion

The AR application promotes understanding of spatial problems, which facilitates students to perform graphic tasks of the subject "Descriptive Geometry and Engineering Graphics". This is especially important for the undergraduate students with a deficiency of basic knowledge of geometry at the very beginning of studies of any engineering subject.

The visualization of 3D tasks makes them less abstract and more understandable for students, and it provides much more positive attitude to the subject and the learning process becomes more attractive.

The students' feedback on the AR-DEHAES toolkit was very positive, and one can conclude that the AR technology may be considered as being a genuine option in the learning process. However, the limited financial resources at the present economic situation at RTU limit a further development and wider application of this technology in the education process.

The training of the spatial ability of students based on engineering graphic contents and AR technology considerably improves using modern ICT. "Descriptive Geometry and Engineering Graphics" course supplemented with AR training elements provides a significant gain in spatial ability scores: 5.33 points for PSVT: R and 11.71 points for DAT: SR, compared to 4.41 points for PSVT: R and 9.21 points for DAT: SR obtained in a conventional or classic engineering graphics course.

The higher is a level of the spatial ability the better is the students' comprehension of engineering graphic contents. When more students will try to improve their spatial skills, e.g. using AR training, a level of academic performance will be considerably higher. AR technology is proved to be effective teaching aid for engineering graphics courses. Applying AR technology to support learning activities may become a trend which will post considerable challenge for the designers and evaluators.

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