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Using 3D Virtual Technologies to Train Spatial Skills in Engineering*

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Engineers are required to have good levels of spatial skills in order to operate in a professional environment. Consequently, we may state that spatial skills are a professional skill which engineers must acquire. In this work, a methodology based on 3D virtual technologies and tools have been implemented in terms of the curriculum of the subject of Engineering Graphics. The experimental study has been carried out with different groups of students from several engineering degrees who studied that subject, using different 3D virtual technologies. Once the subject is completed, the results indicate that there is a significant difference between the spatial ability levels acquired by the groups which had 3D technology support compared with those which didn't. Regardless of the technology used, the improvement is quite similar over both groups, without any significant differences. The academic performance of the students is much better on the part of those groups using these technologies compared with those who complete the course following traditional methods.

Keywords: spatial skills; virtual reality; augmented reality; PDF3D, engineering education; professional skills; professional competencies

1. Introduction

The learning process using conventional methods can cause students to struggle when it comes to memorizing and understanding. When students engage in self-study, they also paradoxically increase their cognitive level. The heavy load of information in the working memory will prevent information being registered in the long term memory while taking part in such an activity [1]. Even when there have been practices conducted for various subjects, it's not possible to perform practically all the contents in the syllabus as they can involve large, dangerous and costly equipment [2]. Bearing this in mind, it is useful having a dynamically cognitive device to overcome this problem, such as multimedia animation or the use of courseware and teaching aids which are both practical and suitable for such topics.

While developing knowledge, students use their mental schema to visualize or develop pictures and images. The visualization is a way of thinking in which images are produced to recall a memory. Among all the definitions that exist, we must underline the inclusion of the ability to manipulate mental images and the ability to interpret visual information in the brain [3].

Spatial ability is one of the most intensely studied skills in the field of human cognition. It has consequences in all scientific and technical fields, and it's still a very active subject in the fields of both psychology and engineering, despite the large amount of investigation and scientific work performed already. It's very common to find a high level of spatial ability in people working in both engineering and architecture related activities [4].

The development of spatial skills by engineering students is directly connected to future success in their professional field [4–6] and is critical for understanding the content of engineering graphic subjects [7]. This capability can be described as the ability to picture three-dimensional shapes in the mind's eye. 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 [8]. However, there is another approach available that is based on the development of specific training for the development of spatial skills.

From our perspective as teachers, we realize what difficulties are experienced by first year engineering students while learning Technical Drawing, mainly because of low levels of spatial ability in engineering, and that's why we feel that there is a need to create tools and methodologies to improve this ability.

2. Engineering and spatial skills

There is evidence which indicates that strong spatial skills are required for achievement in science, tech-

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nology, engineering and mathematics (STEM) careers. Many people, including science and engineering professors, view such skills as important for success in fields like engineering.

An intuitive connection is commonly established between spatial skills and engineering [9]. Many scientific works about spatial abilities or their components, refer to the fact that engineering, architecture and almost every science career demand good levels of spatial ability.

Several teachers and researchers connected to engineering have suggested the need to develop spatial ability as part of the contents of Engineering Graphics subjects [10]. Barr analysed the future curriculum of engineering degrees, bearing in mind the new trends in the 21st Century [11]. In a survey of Engineering Graphics teachers, he pointed out that the subject regarded as the most important is the development of spatial abilities. Other authors who refer to this subject are Ault, Miller and Smith [12–14].

Branott, Hartman and Wiebe developed an introductory course in Engineering Graphics focused on the development of spatial abilities [15]. They also recommended that matters which should be addressed include the following: 3D modelling, orthographic projections, pictorial images and geometry. Dr. Sheryl Sorby became one of the most highly involved researchers into the development of spatial abilities and their increase in engineering students [16–19]. Sorby demonstrated that developing spatial abilities could help engineering students aiming for success in connected subjects and in their future careers.

Field recommends the encouragement of the development of spatial abilities on the part of engineering students, stating that a clear decrease in spatial abilities has arisen among those studying curriculums in which the descriptive geometry contents have been deleted [20]. Contero, Company, Saorín and Naya [21], also describe the importance of spatial thinking in the Engineering Graphic programme. From their perspective, spatial abilities should be emphasized through activities such as orthographic projections or interactive multimedia exercises for the mental processing of 3D objects.

Different researches performed by several authors demonstrate there is a strong connection between good levels of spatial abilities and academic success. Turğut & Ylmaz [22] investigate the link among pre-service primary mathematics teachers' gender, academic success and spatial ability, stating than those people owning better levels of spatial ability obtain better academic results. Meanwhile, Potter & Van der Merwe [23] have performed actions toward improvement of spatial ability in engineering students obtaining a 88% higher pass rate than previous years concluding spatial ability is trainable through adequate methods. This research also indicates that levels of spatial ability prior to accessing university are quite relevant for academic performance. Guidera [24] indicates that level of spatial ability of students is an indicator considered as a predictor of student performance. The authors document the results of a research about the connection between spatial visualization abilities and academic performance for first year engineering and architecture students. In 2009, Potter et al., [25] published the results of a longitudinal study conducted at the University of the Witwatersrand where they demonstrated a "firm and consistent link between three dimensional spatial perception and academic performance in the first-year engineering graphics course."

2.1 Integrating professional competencies into the engineering curriculum

In an academic environment, engineering graphics teachers usually encounter students who have difficulty undertaking tasks requiring spatial reasoning and viewing abilities. In the curriculums of degrees where Engineering Graphic appear (previous to the creation of the framework for qualifications of the European Space for Higher Education Area), no reference was made to any provision of development with regard to a student's spatial ability. As the time available for exploring the contents of the subject is quite short, teachers do not generally consider how a student might be able to develop his/her mental abilities relating to object rotation, spatial reasoning, etc.

Actually, there is a void in the old curriculums of engineering programmes in terms of help for improving the spatial ability of students. If this issue is solved, we may help the students who have some degree of difficulty in understanding the sketching systems, allowing them to overcome this handicap.

In the current curriculums of degrees in the field of engineering based on the framework of the European Space for Higher Education (ESHE), spatial vision capability is presented as a competency that should be developed by students as a foundation for all engineering degrees [26].

The use of technologies applied through a suitable methodology may be included in the curriculums of Engineering Graphic subjects to provide students with a better level of spatial skill. The main aims of this work are: the development of didactic material based on virtual technologies and 3D tools; implementing methodologies which use these didactic materials in engineering degrees; knowing how students behave while using them; and checking if they are of any use in improving the students' spatial skills. The didactic material will be designed in terms of the principle of improving spatial vision abilities, learning graphic engineering contents, and better adaptation of each technology according to the engineering field in which it is to be applied. This implies designing learning activities that follow the philosophies of each one of those three aspects of technology, and implementing them in the classroom to three different groups of students that at operating at the same level.

3. Proposal for the improvement of spatial skills of students: aims and hypotheses

The engineer needs good levels of spatial skills in order to develop his/her professional activity. The spatial skills are not learned, but trained [4, 5]. In this work, we propose the implementation of a methodology which allows such training and development at the same time as Engineering Graphics subjects are taught.

The main aim of this work is to develop tools and didactic materials inside the engineering environment, in order to develop the spatial ability of students from a range of engineering degrees. The spatial skill is essential for complementing other professional abilities. With this new material, our aim will be to integrate methodologies which suit the subjects' curriculum, thereby allowing the students to acquire professional skills.

The research hypotheses in this work are:

H1: The student improves his/her spatial ability, regardless of the methodology and tools used in the engineering graphics subject.
H2: The use of 3D virtual technologies and tools improves the students' spatial skill greatly.
H3: The academic performance increases when students add 3D virtual technologies to their academic tasks.

4. Research design: pilot study

4.1 Measurement of instruments

The spatial aptitude tests consist of instruments for evaluating the level of ability of space visualization on an individual. 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 the same object as a supplied reference or not.

Some of the most accepted theories come from researchers [27, 28] who have proposed three major sub-components 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 [29] and engineering fields [30], are now reduced to just two sub-components:

- *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 two of the most common types of spatial abilities tests, the Mental Rotation Test (MRT) [31] and the Differential Aptitude test (DAT-5:SR) [32], as they are highly valuable tools for performing measurements of spatial skills. The features of these tools are:

- *Mental Rotation Tests*: Execution time is constrained. Their tasks demand comparisons of simple 2D or 3D stimuli for determining if they are representations of the same stimulus or not.
- *Differential Aptitude Tests:* Testing time is not quite short as emphasis is put on precision rather than speed performance. The proposed tasks are mainly focused on the internal manipulation of the stimulus.

4.2 3D visual tools for developing the spatial skill on engineering graphics

During the second semester of the 2011–2012 academic year, under the name Solidworks, the authors developed exercises which aimed to develop the spatial skill of students. The 2D models were adapted for use by several 3D visualization technologies: virtual reality (VR), augmented reality (AR) and Portable Document Format (PDF3D). In addition, several sets of didactic material and app interfaces were created for both work and for the display of these three technologies.

4.2.1 Virtual reality (VR)

Virtual reality is known as the set of technologies and interfaces which allow one or more users to interact in real time with a computer-generated 3D environment or dynamic world. These 3D elements and interactive environments are built through VRML language which has evolved through different versions since its beginning in 1994.

The continuous improvement of tools allowing creation of Virtual reality applications as well as better performance of the technology equipment needed for executing them have become an standard in the training processes of spatial ability. For

Fig. 1. Platform DHS. Levels: basic, intermediate and advanced. Annex: animated machines.

building scenes and worlds through VRML, resources such as low-level programming can be used, as well as the syntax and semantics of language where an ISO spec of language exists as well as a big amount of bibliography. In our case, for developing this virtual world we have used 3D design programs and their VRML export abilities.

The didactic material is composed by forty exercises that were created and distributed in three levels of growing difficulty which are quite similar to those used at pre-university education. Also a annex composed by animated machines and their engineering drawings (Fig. 1). The exercises based on VR are uploaded to a web platform called Draw Help System (DHS). When an exercise is selected, the application shows a piece in the virtual environment allowing its manipulation (movement, rotation or change of position, etc) so the user may become aware of all its details.

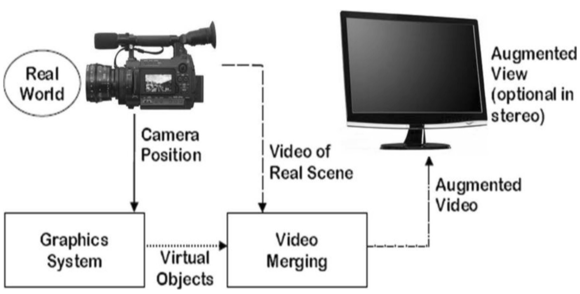

Fig. 2. Augmented reality scenario with personal computer.

4.2.2 Augmented reality (AR)

This is the term used for defining the direct or indirect vision of a physical environment from the real world, which elements combine with virtual elements for creating a mixed reality on real time. It consists on a set of devices which add virtual information to the physical info that already exists. This is the main difference with Virtual reality as it doesn't replace the physical reality but over impose the computer data over the real world. Augmented reality scenario we have proposed for this work consists of the elements that we can see in Fig. 2.

All exercises and pieces were adapted to this format used by the BuildAR Pro augmented reality application which allows creating scenes composed by a set of images or marks that codify a 3D model. When a scene is executed, a webcam connected to the PC recognizes an image which is related to the 3D model and shows it already integrated into the real world. A 'marks book' is also created where the mark is composed by a frame and the exercise's image inside (Figs. 3 and 4).

4.2.3 Portable Document Format 3D (PDF3D)

All PDF files are widely used at many environments in an easy way, commonly just as documents and forms readers. However, the chance of incorporating multimedia objects to these documents is less known. This easy tool is also extended to any device

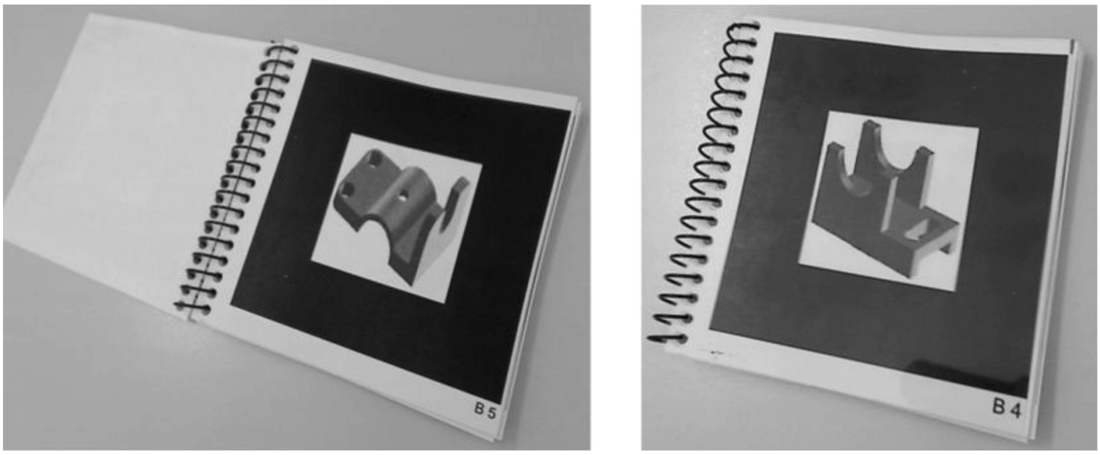

Fig. 3. Marks book

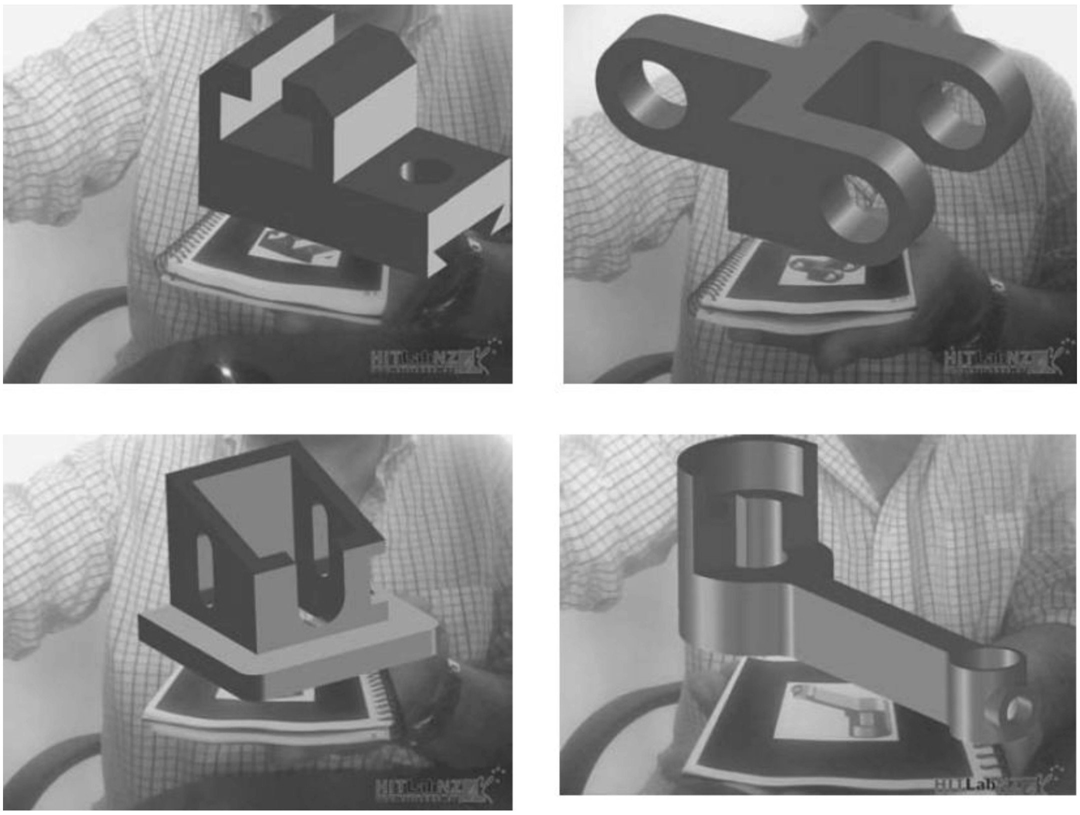

Fig. 4. Rebuilding 4 marks

such as PCs and mobile devices. We propose this support tool in this study due to its accessibility and simplicity.

The PDF format has incorporated the 3D object vision capability inside its multimedia characteristics through the Universal 3D (U3D) format included in its PRO X version. The portable document format (PDF) developed by Adobe Systems has become the information exchange standard from any application or computer system. It has the following characteristics:

- Open standard: the PDF format is an open standard developed under the ISO 32000 norm.
- Multiplatform: the PDF files may be visualized on every platform available including Windows®, Mac OS and mobile platforms such as Android™.
- Extendable: Many providers offer PDF based solutions including creation, plug-ins, consultancies and technical support tools.
- Reliable and secure: the fact that there is over 150 million of PDF documents available for public

use online together with the huge amount of PDF files available in both public and business administration proves that enterprises trust format for information transmission.

- Sophistication for information's integrity: the PDF files have the same aspect and show the same information as the original files like text, drawings, multimedia content, videos, 3D, maps, colour graphics and pictures regardless of the application used for creating them or being compiled in a unique PDF folder from several formats.
- Search capability: the text search tools on documents and metadata ease searching over PDF files.
- Accessibility: the PDF files use support technologies for easing the access to information for people with disabilities.
- Interactive: Its new 3D manipulation capability (U3D) has helped it to become one of the best systems for distributing and sharing graphic information.

The same exercises and pieces were transformed into U3D format used by PDF3D allowing its manipulations in an independent environment (Fig. 5).

4.3 *Experimental study*

During the academic course 2012–2013, several specific strategies for developing the spatial skills of students were implemented in the curriculum of the Engineering Graphics subject. The subject is taught as part of five degree programmes, and it was developed according to the programmes and planning stated in the instructional guide. The subject is mainly practical as the students must work mentally with 3D images. In this subject there are eleven practice groups belonging to those different degrees. This experimental study will consist of teaching practical learning to every student group through the use of 3D viewing technologies. In every group, one of these technologies will be used (virtual reality, augmented reality and PDF3D). In other groups, none of these technologies will be

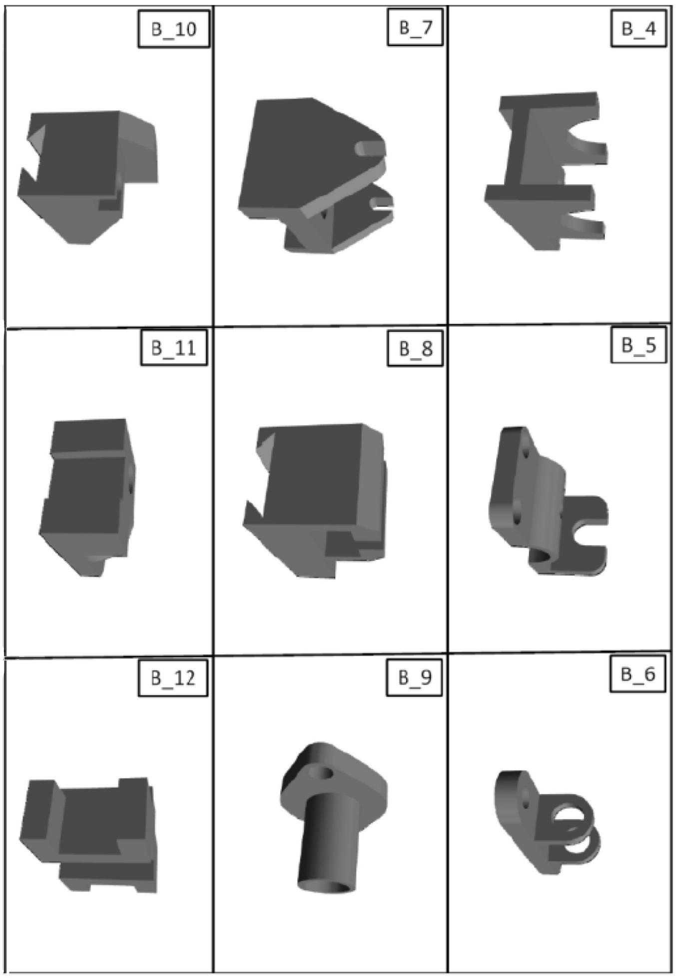

Fig. 5. Interfaz PDF3D.

Table 1. Distribution of groups according to the degree and the technology used

Degree	AR	VR	3D_PDF	Control	N
Industrial Engineering	19	18	19	20	76
Design Engineering	18	19	19		56
Marine Engineering	17				17
Chemical Engineering		16			16
Industrial Organisation Eng.			19	18	37
Total	54	53	57	38	202

Table 2. Mean scores, standard deviation (SD), and number of cases (N) of measures of students' Pre-test spatial ability

	AR Group **N = 54** **Mean (SD)**	**VR Group** **N = 53** **Mean (SD)**	**PDF3D** **N = 57** **Mean (SD)**	**Control Group** **N = 38** **Mean (SD)**
Pre_MRT	15.51 (7.30)	17.89 (6.93)	14.70 (7.32)	14.85 (9.34)
Pre_DAT-5:SR	20.01 (9.56)	29.13 (9.51)	24.74 (8.54)	19.04 (10.35)

used, as practice teaching will be performed in a traditional way, this becoming the 'control group' for the purposes of statistical analysis. At Table 1 we can see the distribution of groups sorted by degrees, and the technology used for training spatial abilities.

At the beginning of the course, the MRT and DAT-5: SR spatial abilities measurement tests were provided. The course was of 15 weeks duration, so each group received the didactic content as determined by the subject curriculum. The difference between groups was the sort of tool or technology which was used for visualizing the theoretical content, and the practical exercises they had to solve. At the end of the course, the spatial abilities measurement tests was performed once again.

The first aim was to find out if the students had developed their spatial abilities based on four different methodologies. The second aim intended to determine if there were any differences in terms of the acquisition of spatial skill between the different methodologies, and how has been influenced on the academic performance of the students.

4.3.1 Participants

In order to analyse the impact of the educational content based on three methodologies on students, 202 students from different engineering degrees of the Las Palmas de Gran Canarias University were involved (Table 1). Every participant in this study was a freshman who hadn't undertaken any previous training in spatial skills.

The students followed the training phase using the same exercises involving three different technologies (VR, AR and PDF3D) and three methodologies accordingly. A total of 53 students used the VR-based tool, 54 students used the AR, and 57 made use of the PDF material available. Besides we made use of a control group of 38 students who didn't undertake any kind of training.

4.3.2 Spatial skills improvement results

The mean values of the MRT and DAT-5: SR tests of the three experimental groups and control group, prior to the course, are very similar.

Table 3 summarises the result of the analysis of variance (ANOVA) for MRT and DAT-5: SR

Table 3. Analysis of variance for MRT and DAT-5:SR between groups

Summary of ANOVA for Pre_MRT

	Sum of Squares	**GL**	**Mean Square**	**F**	**Sig.**
Between Groups	147.196	4	53.9681	0.67	0.6135
Within Groups	36 805.0	197	62.5278		
Total (Corr.)	36 973.6	201			
Total		202			

Summary of ANOVA for Pre_DAT-5:SR

	Sum of Squares	**GL**	**Mean Square**	**F**	**Sig.**
Between Groups	110.836	4	35.2416	0.95	0.4362
Within Groups	39 543.1	197	82.1070		
Total (Corr.)	39 643.7	201			
Total		202			

Table 4. Mean pre/ post test and gain test scores (std. dev.)

	Pre-test		Post-test			
***(SD) Std. dev**	**MRT**	**DAT-5:SR**	**MRT**	**DAT-5:SR**	**Gain MRT**	**Gain DAT-5:SR**
AR Group	15.52	18.80	24.69	31.15	10.31	12.35
N = 54	(8.31)	(8.03)	(9.78)	(9.45)	(5.21)	(5.51)
VR Group	17.75	29.02	23.52	36.29	5.77	7.27
N = 53	(5.64)	(8.19)	(6.27)	(7.63)	(3.28)	(4.69)
PDF3D	14.42	24.49	22.81	36.07	8.39	11.58
N = 57	(7.31)	(8.39)	(7.88)	(8.47)	(5.47)	(7.38)
Control group	13.87	18.97	19.61	25.37	5.74	6.39
N = 38	(4.72)	(6.49)	(7.55)	(7.72)	(4.75)	(3.60)

measure in the four groups (augmented reality group, virtual reality group, PDF3D group, and Control group).

There were no significant differences between groups prior to spatial training ($F_{4,198} = 0.67$, $p = 0.61$ on MRT and $F_{4,198} = 0.95$, $p = 0.43$ on DAT-5:SR). So, all groups were statistically equivalent in spatial visualisation and spatial relation at the outset of this study.

After doing the courses, spatial abilities were measured again. Table 4 and Fig. 6 show the results of the pre- and post-tests as the gain value.

We use the Students' *t*-test in the statistical analysis and our null hypothesis, *H*o, is that mean values of spatial abilities do not vary at the end of the course, meaning that 'the students that do training courses do not improve their spatial skills'. The result of the comparison of mean pre- and post-tests with the Students' *t*-test for paired series is shown on Table 5.

The groups that underwent training with 3D visualization technologies showed an improvement in spatial ability levels. In all three cases studied, the null hypothesis is rejected, which indicates that there is a statistically significant difference between the mean pre- and post-test results. Thus, we can state that the courses have a positive influence on improving the level of spatial ability with regard to the two components "Spatial relations" and "Spatial visualisation".

P-values are around 5% for statistical significance, which indicates that the students have a probability of over 95% of improving their levels of spatial ability when performing the proposed training. Besides, the results show there is no improvement in control group levels. To compare and check if there is any difference in spatial ability levels obtained by groups that underwent training, a Shefflé post-hoc contrast analysis was performed. This allows multiple comparisons between the three groups with a different number of individuals in each group, as seen in the results in Table 6.

Through the paired results, we can state that all

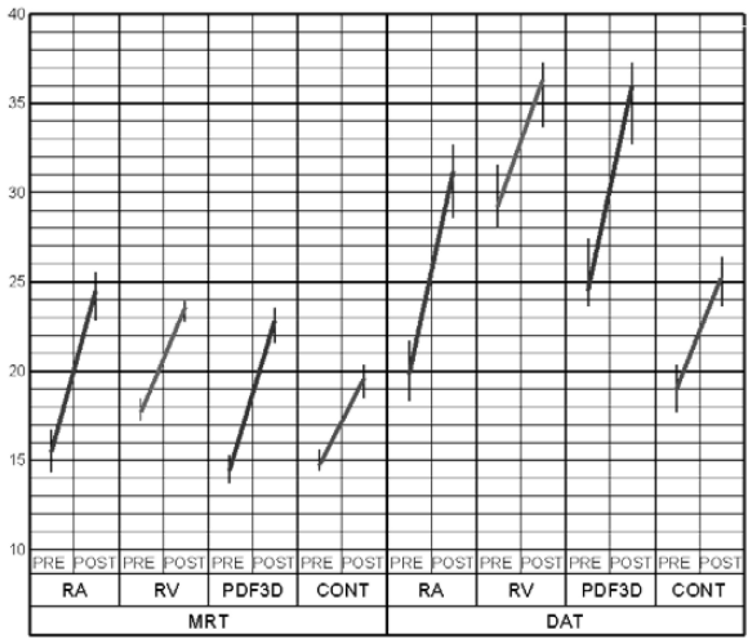

Fig. 6. MRT and DAT-5:SR scores before and after the course.

Table 5. Level of significance comparing pre vs.post-test scores (MRT and DAT-5:SR) within each courses types ad control group

	MRT p-value	DAT-5:SR p-value
Pre_AR - Post AR N = 54	$p = 0.0005 < 0.01$ $t = 3.49$	$p = 0 < 0.01$ $t = 8.43$
Pre_VR - Post_VR N = 53	$p = 0.0001 < 0.01$ $t = 4.768$	$p = 0 < 0.01$ $t = 6.11$
Pre_PDF3D-Post_PDF3D N = 57	$p = 0 < 0.01$ $t = 5.46$	$p = 0 < 0.01$ $t = 10.42$
Pre_Control-Post_Control N = 38	$p = 0.035 < 0.05$ $t = 1.49$	$p = 0.02 < 0.05$ $t = 2.12$

Table 6. Comparison between groups for gain in MRT and DAT-5:SR

Comparison Between Groups for Gain in MRT			**Comparison Between Groups for Gain in DAT-5:SR**		
		p-value			**p-value**
AR_group	VR_group	0.310	AR_group	VR_group	0.077
	PDF3D _group	0.431		PDF3D _group	0.183
	Control_group	0.021*		Control_group	0.000*
VR_group	AR_group	0.310	VR_group	AR_group	0.077
	PDF3D _group	0.284		PDF3D _group	0.637
	Control_group	0.002*		Control_group	0.003*
PDF3D_group	AR_group	0.431	PDF3D_group	AR_group	0.183
	VR_group	0.284		VR_group	0.637
	Control_group	0.001*		Control_group	0.001*
Control_group	AR_group	0.021*	Control_group	AR_group	0.000*
	VR_group	0.002*		VR_group	0.003*
	PDF3D _group	0.001*		PDF3D _group	0.001*

* Difference between averages is significant at 0.05 level.

students involved in training based on 3D virtual technologies improve their spatial skills equally, so there is no statistically significant difference. However, there is an actual difference with regard to such acquisition in terms of the control group. Comparing the control group with the others, there is a significant difference about the level attained in terms of spatial ability. So, there is a significant difference in the acquisition of spatial skills using tools based on 3D technologies.

4.3.3 Effect of the results in terms of academic performance

We then attempted to establish a connection between the technology used for training spatial abilities and the academic performance of the students at the end of the course. In Table 7 we can see the average score and standard deviation of the grades obtained by students from each group in the final exam. The Kolmogorv-Smirnov contrast shows that the grades obtained in each group of students follow a standard distribution. All p-values exceed the 5% significance level.

The homogeneity of the population variance is checked through the Barlett test having in mind that samples have different sizes. The null hypothesis considered is the equality between the mean values of the grades belonging to the students groups.

H_0 = Mean $_{AR}$ = Mean $_{VR}$ = Mean $_{PDF}$ = Mean $_{CONTROL}$.
H_1 = At least two Means are equal.

In the descriptive statistics contained in Table 8, we may observe that the grades obtained by the students who used the AR and VR technologies are almost equal (mean grade: 'pass'). The mean value

Table 7. Groups distribution by technology and qualification

		AR	**VR**	**PDF3D**	**Control**
N		54	53	57	38
Normal Parameters	**Mean**	**5.122**	**5.221**	**5.024**	**4.297**
	Std. Desv	2.413	2.155	2.188	2.087
Differences	Absoluta	0.173	0.141	0.179	0.184
	Positive	0.110	0.087	0.094	0.090
	Negative	–0.173	–0.141	–0.179	–0.186
Z Kolmogorov-Smirnov		1.262	1.006	1.313	1.070
Sig.		0.083	0.264	0.064	0.202

Table 8. Descriptive statistics

	N	Average	Std. Desv.	Typical error	Confidence interval at 95% Upper–Lower limit		Min	Max
AR	54	5.1226	2.4131	0.3314	4.4575	5.7878	0.60	8.20
VR	53	5.2216	2.1553	0.3018	4.6154	5.8278	0.20	8.90
PDF3D	57	5.0241	2.1883	0.2977	4.4268	5.6214	0.10	8.40
Control	38	4,2970	2.0873	0.3633	3.5568	5.0371	0.20	7.10
Total	202	4.9785	2.2335	0.1616	4.6597	5.2973	0.10	8.90

Table 9. Students pass/fail

	3D technologies use methodologies			Traditional methodology		
	>5	<5	NP	>5	<5	NP
Industrial Engineering	33	21	2	7	10	3
Design Engineering	32	22	2			
Marine Engineering	10	7	–			
Chemical Engineering	11	4	1			
Industrial Organisation Eng.	10	8	1	9	7	2

of the grades of the students who trained with PDF3D was lower, some even failing to pass. Meanwhile, the students following conventional teaching methods obtained the worst overall results.

The Levene statistic allows us to contrast the equal population variance hypothesis, which in this case is greater than 0.05 (alpha = 0.427), meaning that variances are the same. Consequently, there were no significant differences between groups in terms of the grades obtained by the students.

Even when there is no difference between grades, it's important to underline that there is a higher rate of pass grades on the part of groups which trained their spatial abilities through virtual technologies rather than those which didn't. In the following graphic (Fig. 7) and in Table 9, the pass and fail grades are sorted according to the use of visual 3D tools or the lack of it.

5. Conclusion

Engineering professionals should be provided with good levels of spatial ability, as this will help him to evolve in their professional tasks. Spatial ability is a component of intelligence, and is an ability that can be trained for, developed or improved. This work incorporates strategies in curriculum engineering degrees in order to develop these skills, as this will benefit the students' understanding of other subjects. It will also be useful for the successful completion of other tasks that demand these skills. The three research hypotheses proposed in this work were accepted, and from them we can state these conclusions.

The students improve his/her spatial skills regardless of the methodology and tools used in the subject of engineering graphics. All groups of students which undertook the subject improved their spatial skill levels. The measurements through MRT and DAT-5:SR tests as well as the statistical study confirmed this.

The use of 3D virtual technologies and tools improve the students' spatial skills greatly. There are significant differences between the groups where 3D viewing techniques were used for delivering the subject, rather than traditional methods. The statistical results don't detect significant differences between the spatial skill levels acquired by the different groups of students that used virtual technologies, so that the use of any of the technologies proposed here has the same quantitative improvement effect in terms of spatial skills. Regarding

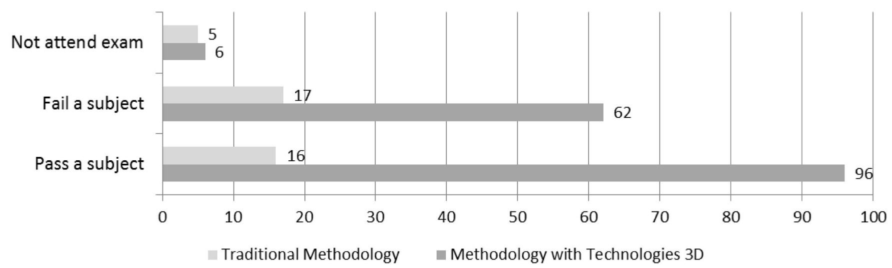

Fig. 7. Number of students passing and failing by methodology.

Academic performance increases refers to, the grades obtained by students on different training groups are analogue. We couldn't claim that there is significant difference between groups , but they are a larger proportion of students using the proposed technologies passed the subject compared with students using traditional methods.

The results point out that over 50% of the students who follow a traditional methodology are not able to pass the graphic design subject meanwhile those groups where 3D tools were used showed pass rates over 60%. The teacher's experience underlines a higher implication on learning as well as the great degree of satisfaction on the part of students when the technologies described in this work were used.

References

1. H. K. Tabbers, R. L. Martens and J. J. G. Merrienboer, Multimedia instructions and cognitive load theory: Effects of modality and cueing, *British Journal of Educational Psychology*, **74**(1), 2004, pp. 71–81.
2. R. V. Bullough, *Creating instructional materials*, Merrill, 1978.
3. S. E. Wiley, Computer graphics and the development of visual perception in engineering graphics curricula, *The Engineering Design Graphics Journal*, **54**(2), 1990, pp. 39–43.
4. G. P. Adánez and A. D. Velasco, Predicting academic success of engineering students in technical drawing from visualization test scores, *Journal of Geometry and Graphics*, **6**(1), 2002, pp. 99–109.
5. C. Miller, A Historical review of applied and theoretical spatial visualization publications in engineering graphics, *Engineering Design Graphics Journal*, **60**(3), 1996, pp. 12–33.
6. S. A. Sorby, Developing 3-D spatial visualization skills. *Engineering Design Graphics Journal*, **63**(2), 1999, pp. 21–32.
7. D. W. S. Tai, S. H. Sun and C. P. Chen, A study of multimedia computer-assisted instruction on problem solving ability and learning performance in engineering drawing, *Proceeding of the 5th UICEE Annual Conference on Engineering Education,* Chennai, India, 6–9 February, 2002, pp. 199–203.
8. M. Alias, T. R. Black and D. E. Gray, Effect of instruction on spatial visualization ability in civil engineering students, *International Education Journal*, **3**(1), 2002, pp. 1–12.
9. E. Ferguson, *Engineering and the Mind's Eye*, Cambridge, Massachusetts: MIT Press, 1992.
10. P. Connolly, Spatial Ability Improvement and Curriculum Content, *Engineering Design Graphics Journal*, **73**(1), pp. 1–5.
11. R. Barr, Planning the EDG Curriculum for the 21st Century: A Proposed Team Effort, *Engineering Design Journal*, **63**(2), 1999, pp. 4–12.
12. H. Ault, 3-D Geometric Modeling for the 21st Century, *Engineering Design Graphics Journal*, **63**(2), 1999, pp. 33–42.
13. C. Miller, New Technologies for Engineering Graphics, *Proceeding of the 53rd Midyear Conference of the Engineering Design Graphics Division of the American Society for Engineering Education.* Columbus, OH, 1999.
14. S. Smith, A Design-Based engineering Graphics course for First-year Students, *Engineering Design Graphics Journal*, **67**(2), 2003, pp. 33–42.
15. T. Branoff, N. Hartman and E. Wiebe, Constraint-Based, Three-Dimensional Solid Modeling in an Introductory Engineering Graphics Course: Re-examining the Curriculum, *Engineering Design Journal*, **66**(1), 2002, pp. 5–10.
16. S. Sorby and J. Barartmans, A Course for the Development of 3d Spatial Visualization Skills, *Engineering Design Graphics Journal*, **60**(1), 1996, pp. 13–20.
17. S. Sorby and R. Gorska, The Effect of Various Courses and Teaching Methods on the Improvement of Spatial Ability. *Proceeding of the 8th International Conference on Engineering Design Graphics and Descriptive Geometry*, Austin, TX, July 31–August 3, 1998, pp. 250–256.
18. S. Sorby, A. Hamlin and N. Veurink, Impact of Changes in Spatial Skills Training, *Proceeding of the 18th International Conference on Engineering Education (ICEE2008)*, Pécs-Budapest, Hungary, 28–31 July, 2008.
19. S. Sorby, Educational Research in Developing 3-D Spatial Skills for Engineering Students, *International Journal of Science Education*, **31**(3), 2009, pp. 459–480.
20. B. W. Field, A course in Spatial Visualization, *Journal for Geometry and Graphics*, **3**(2), 1999, pp. 201–209.
21. M. Contero, P. Company, J. Saorin and F. Naya, Learning Support Tools for Developing Spatial Abilities in Engineering Design, *International Journal Engineering and Education*, **22**(3), 2006, pp. 470–477.
22. M. Turğut and S. Ylmaz, Relationships among preservice primary mathematics teachers' gender, academic success and spatial ability, *International Journal of Instruction*, **5**(2), 2012, pp. 5–20.
23. C. Potter and E. van der Merwe, Spatial ability, visual imagery and academic performance in engineering graphics, *Proceeding of the 2001 International Conference on Engineering Education*, Oslo, Norway, August 6–10, 2001, pp. 7B5(1–7).
24. S. Guidera, Spatial skill assessment as a predictor of student performance in a first year design foundations course, *Proceeding of the 2010 Annual Conference & Exposition*, Louisville, Kentucky, June 20–23, 2010, paper n° AC 2010–1252.
25. C. Potter, W. Kaufman, J. Delacour, M. Mokone, E. Van der Merwe and P. Fridjhon, Three dimensional spatial perception and academic performance in engineering graphics: A longitudinal investigation. *South African Journal of Psychology*, **39**(1), 2009, pp. 109–121.
26. Boletín Oficial del Estado BOE (February 18, 19, 20. 2009) *Órden por la que se establecen los requisitos para la verificación de los títulos universitarios oficiales que habilitan para el ejercicio de profesiones técnicas*. www.boe.es
27. M. Linn and A. Petersen, Emergence and characterization of sex differences in spatial ability: a meta-analysis. *Child Development*, **56**(6), 1985, pp. 1479–1498.
28. D. F. Lohman, Spatial Ability and G. In I. Dennis, & P. Tapsfield (eds), *Human abilities: Their nature and assessment*, Hillsdale, NJ: Erlbaum, 1996, pp. 97–116.
29. J. Pellegrino, D. Alderton and V. Shute, Understanding spatial ability, *Educational Psychologist*, **19**(3), 1984, pp. 239–253.
30. J. Martín-Gutiérrez, J. L. Saorín, N. Martín-Dorta and M. Contero, Do Video Games Improve Spatial Abilities of Engineering Students? *International Journal of Engineering Education*, **25**(6), 2009, pp. 1194–1204.
31. S. G. Vandenberg and A. R. Kuse, Mental rotations: a group test of three-dimensional spatial visualisation, *Perceptual and Motor Skills*, **47**(6), 1978, pp. 599–604.
32. G. Bennett, H. Seashore and A. Wesman, *A Differential Aptitude tests.* The Psychological Corporation, New York. 1947. Spanish official version: Handbook of the DAT-5. Madrid: TEA Ed. 2007.

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