120th ASEE Annual Conference & Exposition
FRANKLY, WE DO GIVE A D*MN
June 23-26, 2013

Paper ID #7024

Tools, Methodologies and Motivation to Improve Spatial Skill on Engineering Students

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Introduction

Ferguson[1] in *“Engineering and the Mind´s Eye”* points out that an intuitive connection is usually established between spatial skills and engineering. Most papers about spatial skills and their components refer to the fact that engineering, architectural and scientific jobs require a good level of spatial ability. Spatial ability has an impact on every scientific and technical field, so it’s still undergoing strong development when it comes to engineering, technology, art and many other aspects of life. It’s quite common to find a high level of spatial ability in people working on either engineering or architectural activities[2].

Graphic design in engineering traditionally had a common aim: teaching all sketching techniques of 3D reality on a 2D surface (paper) to students from different kinds of engineering degrees and backgrounds.

Engineers’ work is developed in environments that all have in common some 3D reality (be it a car or a building) traditionally designed and sketched using two-dimensional methods. Therefore it’s quite important for these professionals to have good levels of three-dimensional vision, as clearly stated in several studies[3,4,5] that underlined the importance of competency in spatial abilities. These are understood to be the cognitive abilities related to spatial factors or capabilities.

The adequate development of these abilities is directly linked to someone’s future success and professional performance[2,6]: that’s why these competences are part of the generic, or transverse, competences in all degrees in the engineering field.

These abilities can be taught like many others as we can learn and improve the level of knowledge and skill that we already have. In this case, this capability can be described as the ability to picture three-dimensional shapes in the mind. Acquiring this ability can be done through an indirect process by means of Engineering Graphics subjects, where students perform sketching tasks and create and read orthographic and axonometric projections[7]. However, there is another approach based on the development of specific training for developing spatial skills.

In the last decade, spatial ability and its development in humans has been widely investigated and studied in order to develop new technologies, methodologies and learning tools to improve students’ spatial skills.

The research team of Dr Sheryl Sorby analysed this issue more than a decade ago in “Why Improve Students’ Spatial Visualization Skills?”[8], focusing her research on the improvement of the spatial skills of students in STEM fields. This was focused on developing these abilities in two specific groups as unfortunately most individuals whose spatial skills are weak tend to be female or from lower socio-economic groups.

From our perspective as teachers we realise that the difficulties first year engineering students have while learning technical drawing are due to low spatial ability levels, so we felt there was a need to create tools and methodologies that could improve this ability.

Training of Spatial Ability

Without any doubt, spatial ability is an important component of human intelligence, but there is no agreement about the sub-factors that compose this component of intelligence[9]. Some of the most accepted theories come from researchers[10, 11] that have proposed three major sub-factors for categorising spatial skills: spatial relations, spatial visualisation and spatial orientation, although some researchers don't recognise spatial orientation as a separate factor. Following classification proposed by researchers from both psychology[12] and engineering[13], it has been reduced to just two sub-factors:

- Spatial relations, defined as the ability to imagine rotations in both two and three dimensions. Authors indicate that this skill includes mental rotation and spatial perception factors.
- Spatial visualisation, which is the ability to recognise 3D objects through the folding and unfolding of their sides. Visualisation is defined as the ability to mentally manage complex shapes.

To measure these components we use the Mental Rotation Test (MRT)[14] and the Differential Aptitude Test (DAT-5: SR)[15], as they are highly validated tools for measuring spatial skills. Spatial ability is something that cannot be taught, but rather trained and that training is the only way to develop and improve it.

Some studies demonstrate that spatial abilities can improve by means of specific training. These abilities in engineering can improve with multimedia exercises, 3D software and other technologies used in graphic engineering[3,16,17,18,19].

Researchers like P. Connolly[20] suggested a need to develop spatial abilities in Graphic Engineering subjects. Barr[21] analysed future academic engineering plans with modern trends in mind and highlighted that the most important subject that should be included in a programme should be the development of spatial skills. Historically there has been a great deal of interest in the methods of instruction and technologies that could potentially increase the spatial skills of its users[22, 23, 24]. Currently, the rise of virtual reality (be it augmented, desktop or immersive) has fuelled the renewed research about the development of spatial ability.

Over the last few years we have performed several studies about fast remedial courses that try to improve the spatial abilities of engineering students in the University of La Laguna in Spain. In these courses, different tools have been tried out: classic exercises (views) using pen and paper; online multimedia web-based exercises; sketch-based modelling through a calligraphic interface[25]; use of Dynamic 3D apps[26]; and videogames as a work tool[17]. The aim is that students who take part in these courses will improve their spatial abilities and help them to have a better understanding of the contents of the subject of 'Engineering Graphics'.

Recently there has been an important evolution in the teaching of Graphic Design in technical degrees. New incoming technologies have been essential in this evolution, determining to a great extent both the teaching and learning processes of this subject. Besides this, the steep rise in the number of students in engineering degrees is starting to make traditional strategies look outdated, such as using physical models, where students can manipulate these with their hands, turning it until they understand them and are able to develop plans to sketch them. This made us plan methodologies to reduce physical models and seek new methods aimed at students who can learn through new computer technologies that they are already used to.

Justification and Aims

In the academic environment, Graphic Design teachers usually see students who have difficulties solving tasks requiring spatial reasoning and viewing abilities. In the curriculums of degrees where Graphic Design appears (previous to the European Space for Higher Education change), reference is made to providing development for a student's spatial ability. As the time available for exploring the contents of the subject is quite short, teachers do not consider how a student may be able to develop their mental abilities relating to object rotation, spatial reasoning etc.

There is a void in the curriculums of Graphic Design programmes of not helping students improve their spatial ability. If that issue could be solved, we may help the students that have greater difficulties in understanding the sketching systems overcome that handicap.

In the curriculums of engineering field degrees in the framework of the European Space for Higher Education (ESHE), the spatial vision capability is present as a competence that should be developed by students as a foundation of all engineering degrees.

The use of technologies applied through a suitable methodology may be included in the curriculums of Engineering Graphic subjects to provide to the students a better level of spatial ability.

The main aim of this work is the development of didactic material based on several virtual and augmented reality formats, knowing how students behave while using them, and checking if they are useful materials to improve their spatial abilities.

The didactic material will always be designed under the principle of improving spatial vision abilities, learning of Graphic Design contents, and better adaptation of each technology according to the engineering field where it should be applied. This implies designing learning activities that follow the philosophies of each one of those three technologies and implementing them in the classroom to three different groups of students that belong to the same level. One of these technologies would be applied to every group and then studied to discover their spatial ability progress, inferring the influence of the tool used in the acquisition of Graphic Design knowledge.

For establishing the possible differences between these technologies, the learning between groups will be compared against a fourth (control) group which will use a traditional methodology. The control group will not use any of the three technologies that are being studied.

Proposed technologies and materials created for training

We have performed an experiment with three different technologies: virtual reality (VR), augmented reality (AR) and portable document format (PDF3D) to find out if they are suitable technologies to improve spatial ability, and from the student's perspective, their opinion of the tool and their motivation to learn more about the aspects of 3D reality.

Virtual reality (VR)

Virtual reality is a set of technologies and interfaces that 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 that has evolved through different versions since its inception in 1994.

The continuous improvement of tools allowing the creation of virtual reality applications, as well as the better performance of the technological equipment needed to execute them, has allowed VR to become standard in spatial ability training.

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

The didactic material is made up of forty exercises that were created and distributed in three levels of increasing difficulty, which are quite similar to those used in pre-university education (figures 1- 4).

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 that allows its manipulation (movement, rotation or change of position etc.) so the user can become aware of all its details.

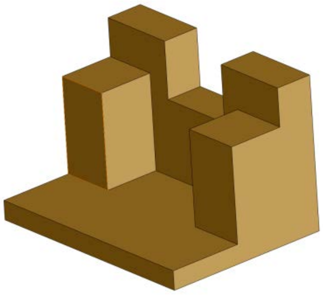

Figure 1. Basic level's piece

Figure 2. Intermediate level's piece

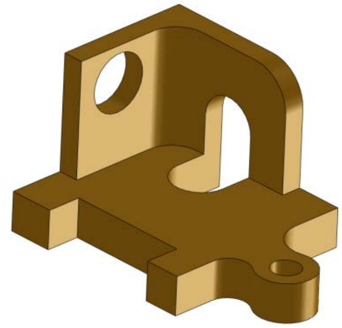

Figure 3. Advanced level's piece.

Figure 4. DHS main window

Augmented reality (AR)

Augmented reality uses either direct or indirect vision of a physical environment from the real world, where real elements combine with virtual elements to create a real-time mixed reality. It uses a set of devices that add virtual information to the physical information that already exists. This is the main difference with VR, as it doesn't replace the physical reality but superimposes the computer data onto the real world.

An augmented reality scenario we have proposed for this work consists of the elements shown in Figure 5:

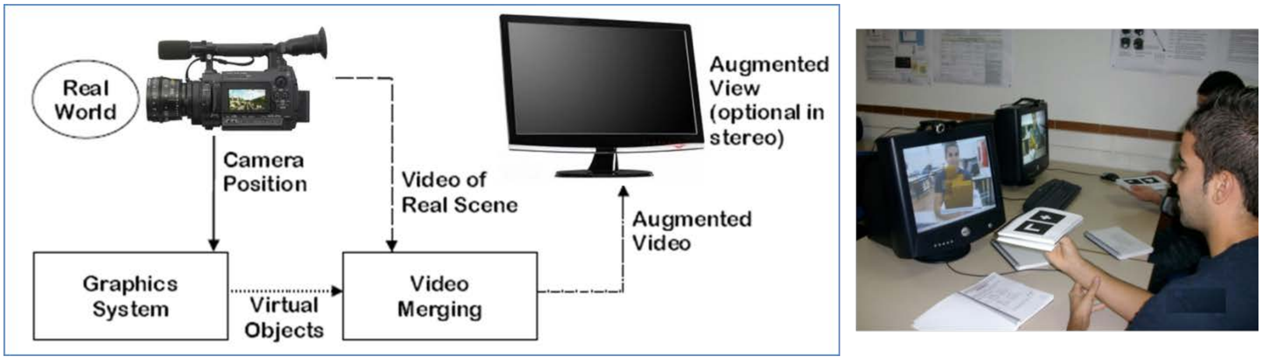

Figure 5. Augmented reality scenario with a personal computer.

All exercises and pieces were adapted to the format used by the BuildAR Pro augmented reality application[27], which allows the creation of scenes made up of a set of images or marks that codify a 3D model. When a scene is executed, a webcam connected to the PC recognises an image that is related to the 3D model and shows it 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 (Figures 6 and 7).

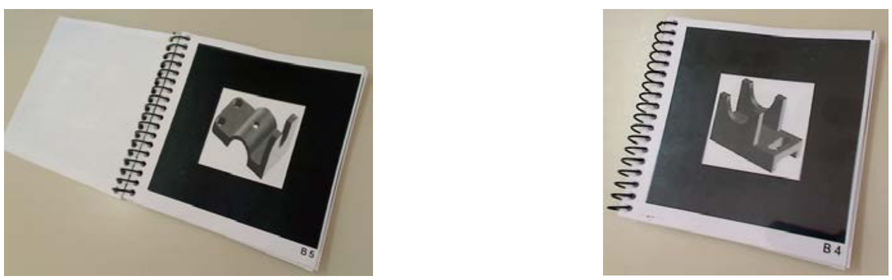
Figure 6. Marks book


Figure 7. Rebuilding four marks

Portable Document Format 3D (PDF3D)

The PDF format has incorporated 3D object vision capability inside its multimedia characteristics through the Universal 3D (U3D) format included in the PRO X version[28]. The portable document format (PDF) developed by Adobe Systems has become the information exchange standard for 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**: PDF files may be visualised 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 are over 150 million PDF documents available for public use online, together with the huge number of PDF files available in both public and business administrations, proves that enterprises trust this format for information transmission.
- **Sophistication for information integrity**: PDF files have the same aspect and show the same information as the original files, such as text, drawings, multimedia content, videos, 3D content, maps, color graphics and pictures, regardless of the application used to create them, or if they are compiled in a unique PDF folder from several formats.
- **Search capability**: the text search tools on documents and metadata ease searching in PDF files.
- **Accessibility**: PDF files use support technologies to increase access to information for people with disabilities.
- **Interactive**: Its new 3D manipulation capability (U3D) has helped it to become one of the best systems to distribute and share graphic information.

The same exercises and pieces were transformed into U3D format used by PDF3D, allowing them to be manipulated in an independent environment (Figure 8).

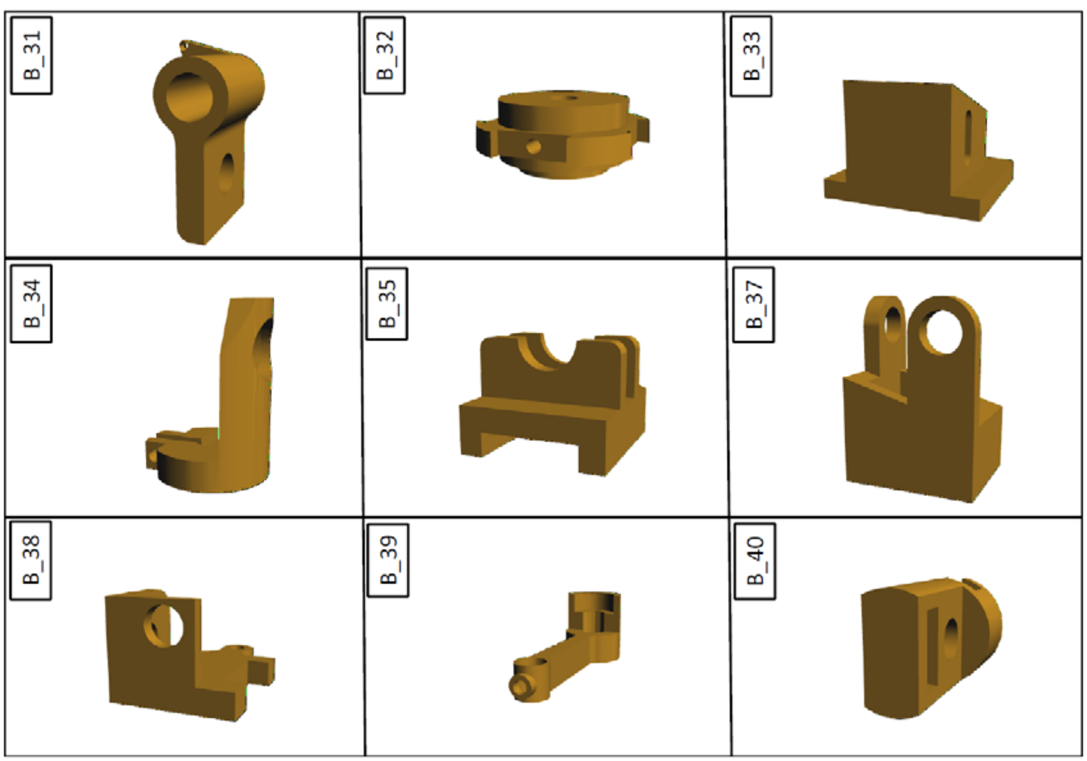

Figure 8. PDF3D interface

The three methodologies have the same aim: the student gets to know the piece, without needing the real model in their own hands, and has all the information needed to sketch the piece and create a workshop contour plan.

The previous tools allow as a student may work on the questions stated in the exercise notebook and practice their sketching abilities.

Experimental study

Participants

A study was undertaken by 57 freshmen studying Graphic Design from the first course in the Industrial Technology degree in the Civil and Industrial Engineering School from the University of Las Palmas de Gran Canarias at Spain. All students completed the training phase using the same exercises using three different technologies (VR, AR and PDF3D) and three methodologies accordingly. An overall of 18 students used the VR-based tool, 20 students used AR, and 19 used the PDF material available. There was a control group of 20 students who didn't undertake any kind of training.

Methodology

The training was performed in the Graphic Design laboratory. The aim was to obtain data about the improvement of spatial ability in the groups using the three methodologies and to find out from the feedback of students their motivation and satisfaction.

The study was performed at the beginning of the 2011/12 academic year, so when they undertook this task these students had not attended any kind of Engineering Graphics classes previously.

The spatial abilities of engineering students were measured before and after training using both the Mental Rotation Test (MRT) and the Differential Aptitude Test (DAT-5:SR). Besides, upon completion of training, the students completed two surveys about their satisfaction with the training and their motivation while performing this experiment.

Only a standard PC and a webcam (for AR) were needed for this training. The students visualised the virtual elements on the monitor. The training had a six hour duration, so they worked on it for two hours per week. The students performed it on their own, although the teacher could help them when needed.

The didactic material was composed of three difficulty levels as shown, so each student performed a level weekly.

Results and analysis of spatial abilities

The mean values of the MRT and DAT-5:SR tests of the three experimental groups and the control group, prior to undergoing the training (pre-test), were very similar (table 1). The analysis of variance (ANOVA) for MRT and DAT-5:SR, measured in the four groups (AR group, VR group, PDF3D group and Control group), showed that there were no significant differences between groups prior to spatial training ($F_{3,74}$=0,654, p=0.583 on MRT and $F_{3,74}$=1,055, p=0,374 on DAT-5:SR). So, all groups were statistically equivalent in spatial visualisation and spatial relation at the start of this study.
After completing the courses, spatial abilities were measured again. Table 1 shows the results of the pre and post-tests scores, as well as the gain for each group.

Table 1. Values Pre/Post Test and Gain

	Pre-test		**Post-test**		**Gain MRT**	**Gain DAT 5:SR**
	MRT	**DAT 5:SR**	**MRT**	**DAT 5:SR**		
VR Group n=18	19.00 (6.40)	30.22 (9.13)	25.33 (7.18)	38.39 (7.85)	6.33 (4.58)	8.17 (6.42)
AR Group n = 20	18.94 (9.79)	24.94 (8.78)	25.67 (10.97)	32.33 (8.76)	6.72 (4.91)	7.39 (3.82)
PDF3D Group n=19	15.47 (7.10)	27.06 (8.33)	23.53 (8.06)	37.65 (7.67)	8.06 (7.59)	10.59 (4,64)
Control Group n=20	17.44 (9.80)	28.40 (10.17)	19.22 (9.91)	33.52 (11.77)	1.78 (4.36)	5.12 (7.13)

We compared the mean values obtained pre- and post-test using the *Student's paired series t-test:*

- VR: MRT t=5.872, p-value=0.00; DAT-5:SR t=5.398; p-value=0.00.
- AR: t=5.81 for the MRT, p-value=0.00; DAT-5:SR t=8.20, p-value=0.00.
- PDF3D: t=4.38 for the MRT, p-value=0.00; DAT-5:SR t=9.41, p-value=0.00.

In the MRT test, the Control Group obtained t=1.88, p-value=0.066; in the DAT-5:SR t=1.718, p-value=0.092.

The groups that underwent training showed a statistically-significant improvement in spatial ability levels. 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 this, 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 LSD Fisher 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 2 and Table 3.

The results confirms that there is a significant difference in the gain between each type of training and control groups, but that there is no difference between the training groups, which underlines the fact that improvement was similar in all groups.

Table 2. Comparison between groups for gain in 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
1,00	**2,00**	1.33660	1.73613	.444	-2.1317	4.8049
	3,00	1.72549	1.73613	.324	-1.7428	5.1938
	4,00	8.05882(*)	1.81851	.000	4.4259	11.6917
2,00	**1,00**	-1.33660	1.73613	.444	-4.8049	2.1317
	3,00	.38889	1.71115	.821	-3.0295	3.8073
	4,00	6.72222(*)	1.79467	.000	3.1370	10.3075
3,00	**1,00**	-1.72549	1.73613	.324	-5.1938	1.7428
	2,00	-.38889	1.71115	.821	-3.8073	3.0295
	4,00	6.33333(*)	1.79467	.001	2.7481	9.9186
4,00	**1,00**	-8.05882(*)	1.81851	.000	-11.6917	-4.4259
	2,00	-6.72222(*)	1.79467	.000	-10.3075	-3.1370
	3,00	-6.33333(*)	1.79467	.001	-9.9186	-2.7481

1 (VR Group), 2 (AR Group), 3 (PDF3D Group). 4 (Control Group)
* Difference between averages is significant at .05 level.

Table 3. Comparison between groups for gain in DAT-5: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
1,00	**2,00**	3.19935	1.71456	.067	-.2259	6.6246
	3,00	2.42157	1.71456	.163	-1.0037	5.8468
	4,00	8.58824(*)	1.79591	.000	5.0005	12.1760
2,00	**1,00**	-3.19935	1.71456	.067	-6.6246	.2259
	3,00	-.77778	1.68989	.647	-4.1537	2.5982
	4,00	5.38889(*)	1.77237	.003	1.8482	8.9296
3,00	**1,00**	-2.42157	1.71456	.163	-5.8468	1.0037
	2,00	.77778	1.68989	.647	-2.5982	4.1537
	4,00	6.16667(*)	1.77237	.001	2.6260	9.7074
4,00	**1,00**	-8.58824(*)	1.79591	.000	-12.1760	-5.0005
	2,00	-5.38889(*)	1.77237	.003	-8.9296	-1.8482
	3,00	-6.16667(*)	1.77237	.001	-9.7074	-2.6260

1 (VR Group), 2 (AR Group), 3 (PDF3D Group). 4 (Control Group)
* Difference between averages is significant at .05 level

Students´ satisfaction

Bevan[29] mentions that in order to make reliable estimations of satisfaction results, 8 to 10 participants are necessary as larger samples offer a more significant value for the success rate. In our study, the evaluation of the material and the software was done by all students (57) who undertook the training.

Once the experiment was finished, they were provided with a survey to find out the level of satisfaction of each group regarding the methodology of the training used. The user's satisfaction was measured using an adapted version of the QUIS Questionnaire30 using a 9 point Likert scale, from 1 to 9. A selection of these questions is shown in Table 4.

Table 4. Users' satisfaction results and questions

	Group		
Question	**VR**	**AR**	**PDF3D**
Terrible-Wonderful	6.2	8.6	6.1
Frustrating-Satisfying	6.0	8.7	7.4
Dizziness-Natural environment	7.3	8.8	6.0
Uncomfortable-Comfortable	5.7	7.1	6.0
Not interesting-Very interesting	6.2	8.6	5.5
Difficult-Easy	8.0	8.5	8.4
Rigid-Flexible	7.1	7.4	6.9
Operation learning: Difficult-Easy	6.1	8.4	7.6
System speed: Too slow-Fast enough	8.1	8.5	8.4
Intuitive system: Not at all-Very much	7.7	8.7	7.0
Overall satisfaction: Low-High	6.9	8.7	6.7
Mean Values	**6.8**	**8.4**	**6,9**

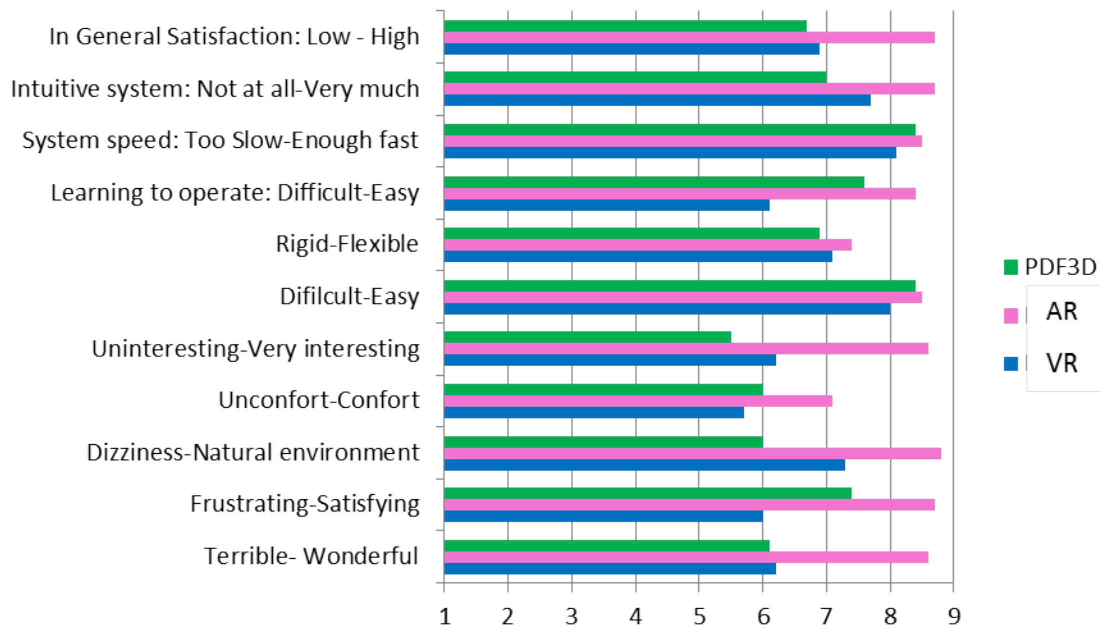

Figure 9. Users' satisfaction results

Measuring motivation of students

In this research work, we regarded the use of a scientifically-validated tool as quite interesting to find out the motivation of students towards the training performed. The learning questionnaire **Motivated Strategies for Learning Questionnaire (MSLQ)**[31] was designed to evaluate university students' motivational orientations and learning strategies.

There are three proposed motivational dimensions related to the learning strategies:

- **Expectations component:** Regarding the student's skill for performing a task.

- **Value component:** Importance given to the performance and interest in the undertaken task.
- **Affective component:** Related to the student's emotional reaction to the task.

Regarding the learning strategies, the MSLQ authors regard three aspects as essential:

- **Metacognitive tasks:** for planning, addressing and modifying the cognitive operation in itself.
- **Control of resources:** Time and location, effort and help from others.
- **Cognitive strategies:** used by students to learn, remember and understand the studied subject.

The latest MSLQ version[32] establishes subscales for every dimension previously described, aiming to analyse in depth the factors that can influence motivation. This version is composed of 81 items, where 31 of them belong to motivational aspects and the other 50 to strategic factors. Each item is answered using a Likert scale of seven levels, where one means no/never and seven means yes/always. Every item is sorted into six motivational and seven strategic scales, as shown on table 5.

Table 5. Distribution of MSLQ scales, dimensions and subscales.

Scales	**Dimensions**	**Subscales**
MOTIVATION	Expectations components	Control beliefs Self-effectiveness
	Value components	Intrinsic aims Extrinsic aims Task value
	Affective component	Anxiety
LEARNING STRATEGIES	Cognitive and metacognitive	Elaboration Organisation Critical thought Metacognition
	Resources management	Study time and location Perseverance/Effort regulation Seeking help and learning with others

For more information about the MSLQ theoretical approach, several previous studies can be read[33,34,35]. Table 6 shows the results obtained for motivational and strategic factors.

Students are mainly guided through their study by aiming toward intrinsic goals as they trust their own learning skills and value the importance, their interest and the usefulness of training. They also realise that any improvement they attain through training depends on their own efforts and that they know they will be able to reach high levels of spatial ability.

Overall, they have reached a satisfactory motivation level. There are positive performance, which is reflected in motivational factors, concretely over the learning strategies scale. It is remarkable that the highest level is in anxiety, possibly as a consequence of insecurity caused by the lack of explanatory material for the proposed activities. The training is made so students can acquire basic knowledge about orthogonal views through their own finds and intuition.

Table 6. Motivation factors (subscales)

Motivational factors	**Mean**	**SD**
Control beliefs and learning self-effectiveness	3,73	1,79
Self-effectiveness performance	3,53	1,40
Orientation towards intrinsic aims	3.98	1.82
Orientation towards extrinsic aims	3.20	1.60
Value of task	3,31	1,98
Anxiety	4,60	1,58
MOTIVATION SCALE	**3,72**	**1,69**
Strategic factors	**Mean**	**SD**
Elaboration	3,31	1,98
Organisation	4,87	1,22
Critical thought	3,42	1,72
Metacognition	3,31	1,98
Use of time and concentration	4,55	1,42
Perseverance/Effort regulation	4,88	1,37
Seeking help and learning with others	5,57	1,26
LEARNING STRATEGIES SCALE	**4,22**	**1,56**

The students reached a good level of development in the learning strategies, but they usually made inappropriate use of them, as can be seen in the values for the strategic factors about learning approaches. Another aspect that should be pointed out is that the most developed strategic factor is help, as a consequence of the collective group work. The value obtained for making the most of the available time was also outstanding, as well as focus, which indicates the need to strengthen orientation towards self-sufficient study.

The metacognition and self-questioning scales show that students have not reached the suitable level over the control of their own study, which shows the need of a teacher’s support to develop critical thought, as well as the link to other contents learned from other areas.

Conclusions

The evolution of technology and the appearance of new teaching techniques have made some methodologies obsolete as they are not properly adapted to modern trends. Teaching methods must evolve and adapt to the new technologies that students are used to, and learning will clearly benefit from this.

The students are digital natives as they are used to all kinds of electronic devices and handling information in many digital platforms. Traditional teaching methodologies can cause boredom and a lack of motivation during the teaching activities.

The use of objects and physical models for working in the classroom are not enough for the volume of students who are currently attending these classes. The computer tools that allow virtual modeling and the handling of 3D objects ease teaching tasks as any piece or figure is available without needing to obtain physical models that can be quite expensive and take longer to create. The modeled object may be implemented in every format, such as virtual, augmented, PDF3D or any other.

We have introduced into the classes of an engineering degree three methodologies based on technological tools and 3D models. Overall, the students were quite satisfied with the tools used to learn. The users enjoyed the simplicity of the apps and pointed out the powerful control of tri-dimensional models. Specifically, those students using AR were more satisfied than those using VR and PDF showing the same values. According to the data observed on site, we note that students who trained using AR felt quite impressed and motivated by the use of a new technology, of which they had no previous contact as they were not aware of it. Therefore, the difference is due to the technology's novelty. The teachers observed that students showed more participation and motivation than those from groups where physical models are used, as passivity and a lack of motivation during learning was quite noticeable.

The students who used multimedia didactic material showed confidence in their own capabilities in developing tasks and showed interest while performing them. The students adopted strategies for planning, learning and understanding the upcoming subject, which denotes a high level of motivation about the work that is being developed.

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