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Developing the Spatial Visualization Ability with a Virtual Reality Tool for Teaching Descriptive Geometry: a Brazilian Experience

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Abstract. Due to the difficulty in understanding and learning Descriptive Geometry, combined with the lack of development of spatial abilities of most freshmen in engineering courses, an innovative tool based on Virtual Reality techniques was developed to support teaching the theme. The central hypothesis tested was whether the use of modern stereoscopic systems in the teaching-learning process facilitates visualization and the understanding of complex spatial situations and therefore supports the development of spatial cognition of students, especially of those with lesser ability. In general, the three student groups analysed showed improvements in the development of their spatial skills ($p < 0.001$). However, a statistically significant difference could not be detected by the analysis of average gains offered by the different treatments used in the experimental research.

Key Words: evaluation methodologies, gender studies, improving classroom teaching, interactive learning environments, virtual reality

MSC 2010: 51N05, 97U50

1. Introduction

With implications found in more than eighty careers [19], spatial visualization ability (SVA) constitutes an important and widespread human cognitive capacity used for almost all daily activities such as positioning, distance and directional relationships of people and objects [5], and problems involving specific cognitive skills [10]. Currently, researchers seek to determine where the spatial visualization ability is constituted, how it contributes to the general human

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intellect, what their ways of interacting with others factors or variables are and, finally, the development and use of methods to measure it.

Among the various areas of human knowledge in which this ability is applied, Engineering is emphasized, as it requires advanced visualization capabilities. Spatial reasoning and visualization are essential qualities for engineers due to their importance in the graphic communication process and the ability of professionals to solve spatial geometric problems. Nevertheless, there is still no consensus on the components that exactly constitute this ability. According to Choi [3], mental rotation and spatial visualization are the two categories of major importance as regards the study of spatial visualization ability. In this context, mental rotation involves the ability to mentally visualize and rotate objects in different positions. Spatial visualization is the manipulation of complex visual problems by imagining the relative movements of the internal parts of an image.

In general, spatial abilities require the individual's ability to maintain an active representation of all parties involved in a spatial task, and the interrelationships between them, while simultaneously rotating the image in his/her mind. In these tasks lies the need to store the constituent parts of the image in the memory, and the simultaneous processing of spatial representations involved through the rotation component [11]. In this line, individuals with low spatial ability usually repeat the rotation process more often than those with a more developed ability because they forget certain intermediate representations of the images involved in the process, which requires its restart. In turn, individuals with high spatial ability hardly rotate the same image more than once, and do so at a higher speed than others.

The differences in the performance of tasks that require spatial cognitive abilities are suggested by several studies reported in the literature [6, 7, 8, 12, 20]. In addition to gender, environmental factors (cultural, social and educational), biological, age, learning styles, brain specializations, faster execution of tasks and efficiency have been studied in an attempt to explain such differences in behavior and performance. By being a theme of scientific research extensively explored, including the study of issues still under discussion mainly by cognitive psychology [2, 5], several types of training have been proposed for the development of SVA, among them, the lessons of Descriptive Geometry (DG). As part of Engineering, the disciplines of Descriptive Geometry and Technical Drawing aim mainly to train the student to communicate through graphic representations, and constitute a tool for solving problems in space, being a valuable working instrument in the educational environment for the development of spatial visualization [21]. Despite its importance, DG is considered a matter of learning difficulty, because freshmen in Engineering courses do not show an adequate development of their spatial abilities, which hinders the understanding and monitoring of activities during the lessons. Although it is proven that the Descriptive Geometry courses aid the development of students' spatial visualization ability, there is no still consensus in the literature regarding the best training to be used for this purpose.

Considering the importance of the theme and evidences that stereoscopy can assist the development of spatial visualization [13], a teaching tool was developed to support teaching Descriptive Geometry based on Virtual Reality (VR) techniques, particularly stereoscopy, called DG@VR.

2. The DG@VR tool (Descriptive Geometry in Virtual Reality)

The DG@VR is a tool to support the Descriptive Geometry teacher, for classroom use, which aims to facilitate the visualization of spatial situations in order to increase students' cognitive ability. The system allows the dynamic execution of three-dimensional geometric constructions, allowing the creation of spatial scenarios by the user [17]. Aiming to increase the perception of spatial relationships between the elements represented, stereoscopic projection was adopted, which provided students with the view of geometry in three dimensions, with depth perception.

This innovative tool is characterized as a low-cost solution and feasible for use by large groups since a technology with passive glasses was adopted. Stereoscopy was used in the development of DG@VR due to the benefits verified with its use and, beyond the perception of depth in images, the localization of the intersection between elements and/or their relative position stands out.

The creation of 3D geometry for several purposes within education constitutes an element of contemporary use in computer graphics tools, and should consider the spatial skills of the individuals involved in this task. Considering that Virtual Reality allows users the capacity to interact with objects and situations often impossible in the real world, this technology provides the opportunity to examine unavailable phenomena in some physical environments. Moreover, VR offers a variety of situations for training and teaching, in which materials and traditional assessments fail [4, 9]. Given the opportunity for trainees to visualize the virtual objects in a natural way, this technology has great potential to increase the use of their multi-sensory, multi-perceptual and multi-dimensional abilities to improve their learning. Thus, the tool represents advancement in the teaching of DG, beyond the conventional manipulation and visualization of the Mongean two-dimensional elements. Figure 1 illustrates a scenario of system usage in the classroom.

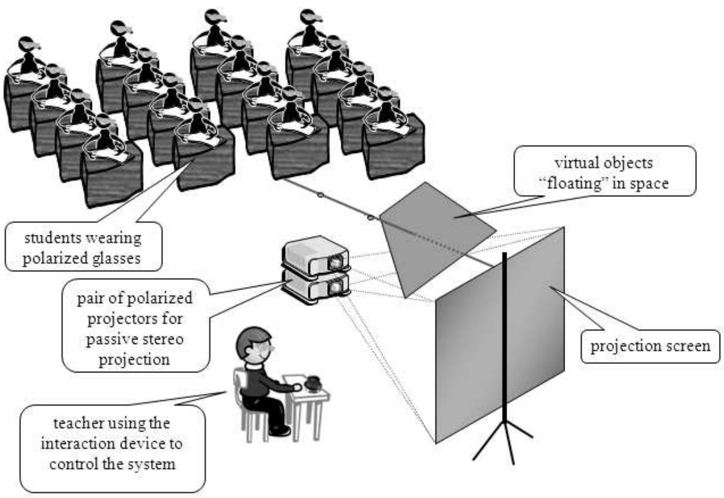

Figure 1: Use of DG@VR in classroom

The system basically uses primitives such as points, lines, planes and projections for the three-dimensional geometric constructions, which occur through the interaction of the user (teacher) with the system input devices: keyboard, 2D mouse and device with six degrees of freedom. The selection of devices was based on the requirements considered essential in the user interaction process with the tool: selection of commands and objects, 3D positioning, 3D orientation and text input. The hardware consists of a pair of polarized video projectors, polarizing filters, glasses with polarizing lenses (which are low-cost and suitable for use by large groups), a silver screen to view the projection preserving the polarization of light, and a graphics card with two video outputs which enables the generation of a pair of distinct images (one for each projector) to obtain the desired effect. Standing out as advantages in the solution adopted is the possibility of 3D visualization by multiple users and no user isolation in the virtual environment.

2.1. Interface

The DG@VR interface has no menus or buttons, like those available in most traditional computer applications. Initially, only a pair of Mongean planes appears on the projection screen (horizontal and vertical projection planes) which acts as a window to an infinite workspace. The system interface consists of the features [18] summarized below.

- *Workspace:* is potentially infinite. It shows the horizontal and vertical planes, with new elements instantiated by the user. The 'virtual camera' is controlled with the 6-DOF device, allowing navigation in the workspace.
- *Pointer:* the MS Windows standard pointer (2D) is part of the system interface. It is controlled with the mouse and used for selection (left button) or pointing positions when creating elements (right button). It can also be used by the teacher to point to any element on the scene when explaining it to students.
- *Elements:* the geometric elements are points, lines and planes. Each element has its own representation. The creation of elements occurs by right-clicking in the desired position in the workspace.
- *Snapping:* a snapping mechanism is implemented in the system allowing precise positioning of elements relative to others. When the system detects that the last selected element is almost parallel, perpendicular or belonging to another element previously selected for snapping, it will adjust its position to precisely reflect that situation. The snapping also works for the camera position, aligning to front, top and isometric views.
- *Projections:* Projections of points and lines are automatically shown in both projection planes when they are selected if commanded using the keyboard. Projection lines are dashed.
- *Element editing:* element editing by using the 6-DOF device, elements can be freely rotated and translated in all three axes. Resizing of planes and lines is performed by dragging the little arrows that appear on them whenever they are selected. Deletion of elements is performed by selection and Delete key pressing.
- *Color and transparency:* the color of selected elements as well as their transparency can be changed by pressing specific function keys.
- *Element labeling:* while an element is selected the text keyed is attached as a floating label near the element.
- *Positioning filter:* to improve control over the positioning of elements, it is possible to filter out the rotation or the translation components of the 6-DOF input.
- *File management:* a scene file to be edited or created may be specified during start-up as a parameter in the command line. Saving is performed by pressing a specific function key.

Finally, DG@VR allows the exploration of DG concepts and spatial constructions involving a Mongean projection system, illustration of theorems and properties, presentation of the main elements (points, lines and planes) of DG and special positions (Fig. 2).

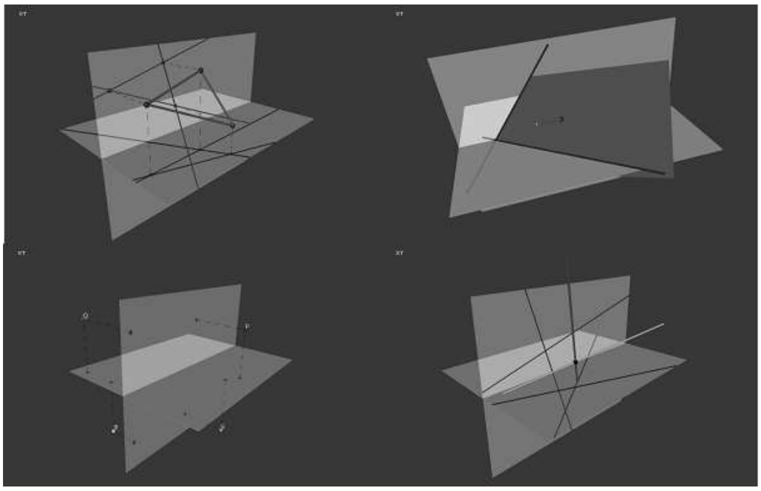

Figure 2: Spatial representations on DG@VR

From the teaching standpoint, it is recommended that the introduction of the system in the classes happens on occasions when the teacher feels difficulty in explaining and representing, by the traditional resources (gestures, paper models or even talking etc.), desired spatial situations. In this sense, DG@VR could be an important instrument to facilitate the visualization process, and its use in the classroom tends to overcome the obstacle regarding visualization, with further development of students' spatial visualization ability based on solving exercises.

3. Purpose of the study

Previous experimental research reports on the performance assessment of students in the TVZ spatial visualization test [1], which was adopted as an instrument to measure their spatial visualization ability in this work. The investigation of the improvement of this cognitive ability was based on different treatments involving the use of DG@VR in the classes of Descriptive Geometry in comparison with conventional classes. Six research questions were formulated as follows:

1. Is the participants' performance influenced by gender ?
2. Did the treatments used promote an increase of students' spatial visualization ability in the three groups ?
3. Did the interactive tool provide a higher gain as compared to conventional lessons ?
4. Did stereoscopy provide a higher gain as compared to conventional lessons ?
5. Did stereoscopy provide a higher gain as compared to interactive tools ?
6. Did the performances of three groups at post-test show homogeneous behavior in relation to the grade obtained in the evaluation of DG ?

4. Methods

4.1. Participants

Ninety-one undergraduate students of DG classes, comprising 75 males and 16 females (mean age = 18 years) randomly divided in three classes, Engineering Graphical Geometry course of the Escola Politécnica of the University of São Paulo (EPUSP), Brazil, taught to first year students in the first half of 2009, voluntarily participated in the experimental research. The three classes were assigned to the same teacher and were classified into three distinct groups: *control group*, *mono test group* and *stereo test group*. The first group received conventional instruction in Descriptive Geometry without the use of the new resources developed. Students in the stereo test group were exposed to the new developed tool using stereoscopic resources during classes with the same content. The mono test group used the same tool, but not operating in stereoscopic mode. PowerPoint slides, prepared for traditional classes, were used with all three groups, as well as the same instruction book.

4.2. Materials and apparatus

The TVZ test was used to measure the students' spatial visualization ability. The test has 18 questions, each involving the unfolding of a cube. The test objective is to identify, among the nine alternatives presented in each question, which letter and in what position it appears on a signed face of the cube, unfolded. Although the creators of TVZ recommend duration of 25 minutes for the test, in this study it was reduced to 20 minutes, aiming at increasing its difficulty. The time reduction was due to the occurrence of saturation effects in the samples analysed in previous studies with the same population [15, 16], and was effective for this purpose. TVZ simultaneously requires the two most important components of SVA of the individuals evaluated: mental rotation and spatial visualization [3]. Both, spatial viewing (for image reconstruction) and mental rotation are needed to detect the face sought, which requires a high processing speed for the association of the image held in working memory with the object spatial visualization.

4.3. Procedure

The procedures and instructions necessary to the test application were the same in the three groups. The study included analyses of three values associated with the independent variable (treatment applied during the intervention process): conventional DG class, class using the tool operating in a non-stereo mode and, class using the tool operating in stereo mode. The main dependent variables controlled in the research are performance of individuals on spatial visualization tests (pre- and post-test) and conventional DG evaluation. The intervention process was conducted for four weeks, and the TVZ was administered to students in the week preceding the first DG class. Before applying the pre-test, students signed a form of consent. The classes were offered to three groups in a lab with good lighting conditions and temperature, and they were conducted in an 8-hour course. The post-test was administered immediately after the intervention process.

5. Experimental results

5.1. Pre-test

For testing the formulated hypotheses, it was necessary to analyse the behavior of the dependent random variable *TVZ score* in different contexts (Table 1).

Aiming to verify whether the variances of the students' scores in pre-test are homogeneous for the three groups studied, we applied the Levene test ($p = 0.931$). The result shows that the test did not reach a significant level and hence, the variances of the groups can be

Table 1: Statistics for the pre- and post-tests on the three groups

		TVZ (pre)	TVZ (post)	Gain
Control group	**Potential range**	0–18	0–18	-18 to 18
	Measured range	1–18	1–18	-4 to 10
	Average score (N*)	7.77 (31)	11.16 (31)	3.39 (31)
	Std. Deviation	4.93	5.76	3.42
	KS (*p*-value)**	1.05 (0.220)	0.85 (0.454)	0.52 (0.950)
Mono test group	**Potential range**	0–18	0–18	-18 to 18
	Measured range	0–18	2–18	-3 to 11
	Average score (N*)	8.31 (29)	12.28 (29)	3.97 (29)
	Std. Deviation	5.25	6.02	3.98
	KS (*p*-value)**	0.43 (0.991)	1.43 (0.033)	0.794 (0.554)
Stereo test group	**Potential range**	0–18	0–18	-18 to 18
	Measured range	0–18	0–18	-6 to 9
	Average score (N*)	6.68 (31)	10.48 (31)	3.81 (31)
	Std. Deviation	5.04	5.59	3.67
	KS (*p*-value)**	0.81 (0.519)	0.68 (0.744)	0.684 (0.738)

Note: *N = Sample size **Kolmogorov-Smirnov Test

assumed to be homogeneous. The obtained $p = 0.447$ in the analysis of variance indicates that there is no significant difference between group means and that they have homogeneous behavior before training. Also in the pre-test, each group was further subdivided into three subgroups, identified as: Subgroup 1 – Low Ability (score range 0–6 points); Subgroup 2 – Intermediate Ability (score range 7–12 points); Subgroup 3 – High Ability (score range 13–18 points), according to data presented in Table 2. This subdivision is related to changes in performance of groups with extremely low or high pre-test. Aiming to isolate the gains obtained from the treatment in each group, and considering that individuals who already had their SVA well developed in the pre-test could not significantly improve their results, analysis of subgroups allowed isolating these possible extremes, and indicate whether subgroups with low and intermediate ability improved their performance, even more so because they constitute the main target of this tool.

Table 2: Distribution of subgroups after the pre-test

		n	% Total	Mean	SD
Subgroup	**1–Low Ability**	46	50.5%	3.46	1.90
	2–Intermediate Ability	27	29.7%	9.22	1.78
	3–High Ability	18	19.8%	15.61	1.65
	Total	91	100.0%	7.57	5.06

Note: TwoStep Cluster

The analysis of the variance test showed no significant difference between the averages of the corresponding subgroups of each group, and that they have homogeneous behavior (low, $p = 0.258$; intermediate, $p = 0.953$; high, $p = 0.496$). Finally, to examine whether the subgroups in each group are heterogeneous among themselves, a test was applied as a more robust alternative to ANOVA [14], Welch's test. Since p <0.001 of multiple comparisons by Scheffe's method, the performance of subgroups that constitute each group was observed to be heterogeneous.

5.2. Post-test

A possible significant difference in participants' performance on the basis of gender was investigated, and analysis showed that SVA shows to be different in the three groups for each gender (Table 3). According to the data presented, it appears that gender influenced the participants' performance, with improved performance for the men from the control and stereo test group, even after the course. The data analysis allowed the observation of an interesting result in the mono test group. Contrary to expectations, women in this group outperformed the males pre- and post-test. This is due to the outstanding female performance in the pre-test ($t = 2.62,\ p = 0.014$), with a better mean score than the post-test male performance in all three subgroups. Unfortunately, we had no chance to further investigate the cause of this anomaly.

Table 3: Comparison of performance by gender

	Female (pre-test)		**Female (post-test)**		**Male (pre-test)**		**Male (post-test)**		**Test* (pre-test) (p-value)**	**Test* (post-test) (p-value)**
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**		
Control	3.75	2.21	4.50	5.68	8.37	4.97	12.15	5.17	-1.812 (0.080)	-2.727 (0.011)
Mono test	12.43	5.74	16.43	2.69	7.00	4.46	10.95	6.22	2.620 (0.014)	2.239 (0.034)
Stereo test	1.80	1.30	4.40	4.50	7.62	4.95	11.65	5.05	-2.574 (0.015)	-2.983 (0.006)

Note:* Student t test for independent samples SD = standard deviation

Similar statistical analysis was performed to detect a possible increase of students' spatial visualization ability in the three groups as a result of the intervention process. According to the analysis, the three groups had a significant increase in their scores ($p < 0.001$). The next research question examined whether the lessons taught to the mono test group provided a greater gain in the development of spatial ability in this group as compared to the control group. No significant result was detected, $t = -0.604$ and $p = 0.548$, indicating that both groups showed equivalent behavior after treatments. Likewise, no significant differences could be detected between the gains of the stereo test group and control group ($t = -0.465,\ p = 0.644$) or between the mono and stereo test groups ($t = 0.161,\ p = 0.873$). Given no detection of significant differences between groups, we analysed the number of participant transitions from each subgroup (low, intermediate and high) to others, possibly due to the treatments used. Figure 3 shows the transitions of participants between subgroups.

According to Fig. 3, there is an increase in the number of students being promoted from the low ability subgroup to the other subgroups with greater ability. This occurred for all three groups, particularly for students from the stereo test group (10 students), what highlights the

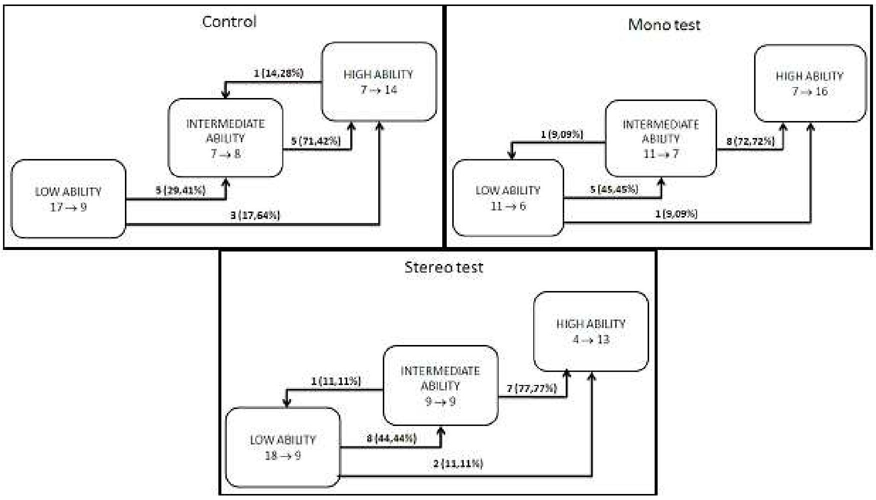

Figure 3: Participant transitions between subgroups of each group

success of treatments. With respect to transitions of participants between subgroups, the percentage of students promoted from the low ability subgroup to other groups was greater in the stereo test group (55.55%). For the control group this transition represented 47.0% and in the mono test group it was 54.54%. The same occurs for the participants promoted from the intermediate ability subgroup in the stereo test group (77.77%). For the control group, the transition represented 71.42% and for the mono test group it was 72.72%.

Finally, the last analysis examined whether the variance of the students' scores in the Descriptive Geometry assessment were homogeneous for the three groups analysed. We used the standard mid-term test as an evaluation tool that was applied to the three groups and which included 4 questions covering the content studied in the four weeks preceding the course. We compared the average total score obtained by each group; the maximum possible score in the assessment was 10. Table 4 presents the summary statistics according to the groups. From $p = 0.004$ of analysis of variance, there was a significant difference between the means of groups. The multiple comparison via Scheffe's method showed heterogeneous behavior in two pairs of comparisons (control x stereo, $p = 0.047$, and mono x stereo, $p = 0.005$). The difference was not significant for the remaining pair (control x mono, $p = 0.681$).

5.3. Qualitative Evaluation

The conducted qualitative evaluation consisted of a questionnaire to collect data for evaluating the opinion of students on the various resources used in the classroom. It is worth mentioning that this assessment also helped in the evaluation of other attributes, since the participant could report important considerations about the treatments used, expressing a different view from all those involved in the project.

The questions prepared and answered by the students used a Likert scale or a yes/no choice to minimize the inherent subjectivity in response to an open question, and streamlined the fulfillment process. In addition to the data collected, participants included some valuable and pertinent comments about their experience. In this regard, the neutrality and impartiality of students enriched the research, allowing the authors a better assessment in terms of the intervention procedures used in the classroom, from the students' perspective. Tables 5 to 10 show the response data for the qualitative evaluation questions.

Table 4: Statistics for the evaluation of Descriptive Geometry

		Evaluation of DG
Control group	**Potential range**	0 – 10
	Measured range	3.6 – 10.0
	Average score (N*)	7.08 (25)
	Std. Deviation	1.90
	KS (p-value)**	0.63 (0.811)
Mono test group	**Potential range**	0 – 10
	Measured range	4.4 – 10.0
	Average score (N*)	7.56 (25)
	Std. Deviation	1.66
	KS (p-value)**	0.84 (0.476)
Stereo test group	**Potential range**	0 – 10
	Measured range	2.0 – 10.0
	Average score (N*)	5.65 (21)
	Std. Deviation	2.18
	KS (p-value)**	0.50 (0.962)

Note: *N = Sample size **Kolmogorov-Smirnov Test

The first question of the qualitative assessment (*"Did you manage to see the spatial situations presented by the system used?"*), applied to the mono and stereo test groups, showed the new tool is effective for presenting 3D scenes to students (Table 5).

The second and third questions to the stereo test group (*"Did you feel some discomfort in the use of 3D glasses?"* and *"Did you use the 3D glasses constantly for visualizing the spatial situations presented?"*) aimed at identifying possible troubles in the use of stereoscopic glasses, and the constancy in their use in the classroom. The result showed that the majority of participants did not feel any kind of discomfort with the use of the 3D glasses, and the rest reported that they felt a kind of eye irritation at certain times. In question 3, only 16.13% (5 participants) of the sample stated that they did not wear the 3D glasses constantly for visualizing the spatial situations presented (Table 6).

With regard to the aid of the stereo effect to display the spatial situations provided, 74.19% of participants approved the use of the system (see Table 9, first line).

The next question compared the ease of visualization of spatial situations presented in the

Table 5: Results from the question
"Did you manage to see the spatial situations presented by the system used?"

	Yes	**No**
Mono test group	100% (29)	0% (0)
Stereo test group	100% (31)	0% (0)

Table 6: Results from qualitative evaluation form. Responses from Stereo Test Group.

	Yes	**No**
Did you feel any discomfort in the use of 3D glasses?	12.90% (4)	87.10% (27)
Did you use the 3D glasses constantly for visualizing the spatial situations presented?	83.87% (26)	16.13% (5)

DG course-book with that in the new system, with and without the stereo effect. The control group evaluated the book in this regard and the majority (45.16%) was neutral (Table 7, first line). Both control groups, on the other hand, agreed or strongly agreed that the visualization of spatial situations presented by the system was more easily understood than the book images (Table 8, first line / Table 9, second line).

The same question was made about the slides used in class. In the control group, the majority (67.74% – Table 7, line 2) agreed or strongly agreed that the visualization of the spatial situations presented in the slides could be easily understood. Nevertheless, more than 80% (Table 8, line 2 and Table 9, line 3) of both test groups stated the new system makes visualization even easier than with just slide images.

Then, participants were asked about learning the course content based on the spatial situations used in the classroom. The best result was observed in the stereo test group, with 77.41% (Table 9, line 4) of participants agreeing that the spatial situations presented by the system provided a better learning of the course content, followed by the responses of participants from the mono test and control groups where the majority also agreed (61.61% and 58.06%, respectively) (Tables 7 and 8, line 3).

Most students of the control group (74.19%) (Table 7, line 4) think the slides presented

Table 7: Results from qualitative evaluation form. Responses from Control group.

	Strongly agree	**Agree**	**Neutral**	**Disagree**	**Strongly disagree**
The visualization of spatial situations presented in the ***course book*** *can be easily* ***understood****.*	12.90%(4)	32.26% (10)	45.16% (14)	3.23% (1)	6.45% (2)
The visualization of the spatial situations presented in the ***slides*** *can be easily* ***understood****.*	19.35% (6)	48.39% (15)	22.58% (7)	6.45% (2)	3.23% (1)
The ***spatial situations*** *presented provided a* ***better learning*** *of the course content.*	19.35% (6)	38.71% (12)	25.81% (8)	12.90% (4)	3.23% (1)
The ***visual resources*** *of the spatial situations presented were of* ***good quality****.*	22.58% (6)	51.61%(16)	25.81% (8)	0.00% (0)	0.00% (0)
The ***resources*** *used in the DG lessons were adequate.*	3.23% (1)	70.97% (22)	22.58% (7)	0.00% (0)	3.23% (1)

Table 8: Results from qualitative evaluation form. Responses from Mono test group.

	Strongly agree	**Agree**	**Neutral**	**Disagree**	**Strongly disagree**
The visualization of spatial situations presented by the system are ***more easily understood*** *as* ***compared to the 2D images of the book****.*	31.03% (9)	55.17% (16)	13.79% (4)	0.00% (0)	0.00% (0)
The visualization of spatial situations presented by the system are ***more easily understood*** *as* ***compared to the 2D images of the slides****.*	20.69% (6)	65.52% (19)	13.79% (4)	0.00% (0)	0.00% (0)
The ***spatial situations*** *presented provided a* ***better learning*** *of the course content.*	17.24% (5)	44.38% (13)	27.59% (8)	10.34% (3)	0.00% (0)
The ***visual resources*** *of the spatial situations presented were of* ***good quality****.*	24.14% (7)	65.52% (19)	10.34% (3)	0.00% (0)	0.00% (0)
The ***resources*** *used in the DG lessons were adequate.*	41.38% (12)	44.83% (13)	13.79% (4)	0.00% (0)	0.00% (0)

were of good quality, but even better results were obtained from students in the mono and stereo control groups regarding the new system (89.66% and 83.87%, respectively) (Table 8, line 4 and Table 9, line 5).

An important issue addressed in the study refers to whether the visualization of the spatial situations presented suffered some type of harm as a result of students' position in the classroom. Regarding this matter, 35.48% of participants in the stereo test group reported thinking their seating position in class was disadvantaged, unlike other groups that reported lower levels on this question (Table 10). It is worthy to notice that the use of polarizing glasses reduces light intensity received by the eyes, as a part of them is filtered out. The silver screen, necessary for preserving light polarization, also acts as a mirror, reflecting light more intensely to viewers right in front of it and dimmed to viewers' off-center, aggravating the problem.

Finally, the last issue of the qualitative evaluation (adequacy of the resources used in the DG lessons) reached good levels of acceptance. For the control group this rate was 74.2%. Again, there were better results for the mono and the stereo test groups. In the first test group, 86.21% agreed the resources were adequate (41.38% strongly agreed) (Table 8, line 5). In the second group the index reached 83.87% but, unlike what was expected for this group, the percentage of participants who strongly agreed was lower (25.81%), as compared to the previous group. The difference may be explained with reference to some reported problems with the display of the stereo effect on the far sides of the room (according to the students' opinion).

Table 9: Results from qualitative evaluation form. Responses from Stereo test group.

	Strongly agree	**Agree**	**Neutral**	**Disagree**	**Strongly disagree**
*The **stereo effect** helped in the visualization of the spatial situations presented.*	19.35% (6)	54.84% (17)	16.13% (5)	6.45% (2)	3.23% (1)
*The visualization of spatial situations presented by the system are **more easily understood** as **compared to the 2D images of the book**.*	45.16% (14)	35.48% (11)	16.13% (5)	0.00% (0)	3.23% (1)
*The visualization of spatial situations presented by the system are **more easily understood** as **compared to the 2D images of the slides**.*	19.35% (6)	51.61% (16)	19.35% (6)	6.45% (2)	3.23% (1)
*The **spatial situations** presented provided a **better learning** of the course content.*	25.81% (14)	51.62% (11)	16.13% (5)	6.45% (1)	0.00% (0)
*The **visual resources** of the spatial situations presented were of **good quality**.*	19.35% (6)	64.52% (20)	16.13% (5)	0.00% (0)	0.00% (0)
*The **resources** used in the DG lessons were adequate.*	25.81% (8)	58.06% (18)	12.90% (4)	3.23% (1)	0.00% (0)

Table 10: Results from the question "Did the visualization of spatial situations presented suffer some type of harm due to your position in the classroom ?".

	Yes	**No**
Control group	19.35% (6)	80.65% (25)
Mono test group	6.90% (2)	93.10% (27)
Stereo test group	35.48% (11)	64.52% (20)

6. Discussion

After the pre-test, the first analysis involved the application of the variance homogeneity test, which did not reach a significant level, concluding that the three groups analysed showed homogeneous behavior in relation to performance in the TVZ. Then, it was found that the subgroups corresponding to each group also showed homogeneity after the clustering process. Therefore, it was necessary to verify whether the clustering process generated heterogeneous subgroups among each other. The multiple comparisons via Scheffe's method showed a significant difference between the means of subgroups, concluding that they are heterogeneous as compared to each other.

As a first analysis of the post-test, there was the influence of gender on participants' performance. From the data collected, it was observed that only in the pre-test control group the performance was not affected by gender. The analysis of the influence of gender allowed the observation of an interesting fact in the mono test group. The women of that group showed better performance than the men in both pre- and post-tests, which contradicts several studies systematically reported in the literature on the theme [6, 8, 20]. This result can be explained by those particular women having achieved an excellent performance in the pre-test, with higher score than the average post-test male performance on all three groups. Based on the results observed in case studies in this research, as reported in the literature, it is believed that this anomaly can be attributed to a coincidence despite the random distribution, sampling many women which high spatial visualization ability in the same group.

The next analysis meant to investigate whether the treatments employed promoted a significant development of participants' spatial visualization ability. The observed results showed that there was a significant increase of SVA for all three groups. Thus, we concluded that the employed treatments promoted an increase in participants' spatial visualization ability. From the improvement detected, the study focused on dealing with three issues related to the gain observed in each treatment. In this line, the average gain obtained by the stereo test group was expected to be higher than that observed in the mono test group, which, in turn, was supposed to be greater than that of the control group. Such assumptions took into account important variables aggregated to the process, such as the motivation for the use of a new computational tool in the teaching-learning process and the advantage provided by the system in the visualization of the spatial situations presented. Contrary to expectations, the difference that would support the hypothesis was not significant. Thus, the analysis of average gains of the subgroups of each group showed no significant differences in the gains. Then, the transitions of participants between subgroups of each group were analysed. The data showed a larger number of participant transitions (55.55%) from the low ability group, especially in the stereo test group, with average gain of 4 points in the TVZ. This result, coupled with the qualitative evaluation, favors the use of DG@VR in the development of lower-skilled students' spatial visualization ability.

Another factor considered in the post-test consisted in analysing the students' performance in the DG evaluation, applied after the end of the intervention process, in an attempt to identify differences in performance in relation to the theme studied. The analysis showed that the performance in DG evaluation showed heterogeneous behavior in two pairs of comparisons, probably due to the lower performance of the stereo test group as compared to the others. At this point, it is worthy to note that the mono test group performed better than the others, followed by the control group. In the last position came the stereo test group.

Based on the lower performance of the stereo test group in the DG evaluation and the TVZ, the existence of other factors outside the experimental research is clearly shown, which possibly influenced the outcome more than the interventions employed in the classroom. Among the possible explanations for this difference, one might think that one of them relates to the dedication of students to other disciplines of the course. As the discipline of Engineering Graphical Geometry is taught by several teachers, the other disciplines of the Engineering course also have the same feature. As teachers can vary, possibly the students of the stereo test group devoted more study to some other discipline over the DG course. This may have been caused, for example, due to a greater demand for some other discipline, whose teacher influenced those students to devote more time to it outside the normal schedule of classes. Thus, participation and performance in the DG course may have been affected.

An alternative to the experimental model used in the study could be to focus solely on the evaluation of exercises solved in class. This is because the tests measure only the visualization of students' spatial visualization ability based on cognitive processes intrinsic to each individual. In this process, all students participating in the sample are analysed according to this aspect, i.e., only taking into account their level of spatial ability. However, one must also consider that many students who participated in the review process had not properly solved the exercises, and this performance is considered in the overall analysis. Based on these remarks, it is believed that a new experimental research in this direction should be conducted. As a way of encouraging the practice of exercises and simultaneously monitoring participants who actually do them, the experiment should provide a controlled character in the classroom, and totally focused on the individual difficulties of students present in the study. Thus, at every activity of the teacher in the classroom (independent group), one should check whether the students succeeded in solving the exercises required. As the tool used in the study aims to facilitate and develop the view of the projective representation and then to allow the student to devise a solution to the problem, the capacity measurement mentioned reflects the advancement in students' ability in this task. Finally, after overcoming this phase, the process of solving exercises will present a greater chance of success in the development of students' spatial visualization ability, possibly with the detection of significant improvements in the mono test and in the stereo test groups, aided by additional resources provided by DG@VR.

7. Conclusion

Spatial visualization ability presents itself as a valuable human cognitive skill to the professional practice of the engineer, and the disciplines of Engineering Design Graphics have enormous potential for the development of spatial cognition. One of the topics covered in the content of these disciplines relates to Descriptive Geometry, which is the main tool for training the intellectual ability of students in the perception of space. Virtual Reality, explored in various areas of knowledge, among them education, includes interface technologies that exploit multi-sensory channels, giving users the capacity to navigate and interact in a three-dimensional space generated by computer processing.

The VR environment used in this study gives users the ability to manipulate and interact with objects positioned in space in any orientation. Although DG makes use only of planar representations (2D), its teaching can be benefited by this interaction process. Furthermore, some VR environments make use of stereoscopic technology, which refers to the capacity to see in three dimensions through the perception of depth in pictures. For this reason, and based on the advantages arising from the use of VR in education, the study in question presented the effects of using DG@VR as an innovative tool to support the DG teaching based on VR techniques, especially stereoscopy. The final conclusion of the study, considering the results of quantitative and qualitative evaluations, and in response to the central hypothesis, is that the use of modern interactive systems in the teaching-learning process facilitates visualization. However, we cannot state that the development of spatial cognition of students benefited from using stereoscopy, and further studies are needed for a conclusive observation, as there are stronger factors affecting the student's final outcome, regarding learning of DG and performance in SVA tests. Finally, it is believed that the tool developed in its first version can be deployed and operated to support the DG teaching in other institutions, contributing to the learning of the theme and to the advancement of teaching methods, adapting them to technological reality experienced today.

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