Exploring Virtual Reality in Classroom for Teaching and Learning of Descriptive Geometry

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Abstract:
Spatial visualization ability is an important skill for the engineering practice. Engineering Design Graphics courses have a great potential for developing spatial cognition. A common topic of these courses is Descriptive Geometry, which is one of the main tools for training students’ spatial perception. Based on these assumptions and on the advantages of using Virtual Reality for education, this paper describes the DG@VR, an innovative tool for supporting Descriptive Geometry teaching, as well the results of an statistical evaluation of this tool, conducted with engineering students.

Key words: Virtual Reality, Descriptive Geometry, Stereoscopy, Spatial Visualization Ability, Teaching.

1 Introduction

Descriptive Geometry (DG) is a hard-to-learn topic for many students and is a drop-out factor for engineering freshmen. Besides the inherent difficult of this topic, these students usually do not have well developed spatial skills [1, 2], making learning harder as well as following most DG-related classroom activities, which depend on spatial visualization abilities. Therefore, increasing students’ spatial skills is a challenge to teachers.

The motivation for developing the educational tool proposed in this paper is on the potential of stereoscopy to make easier the visualization of spatial situations presented on DG exercises as well for increasing students’ interest on this topic, as it is a fun technology. Besides that, this tool represents an advancement on DG teaching as it goes beyond the conventional 2D viewing and manipulation of elements. Also, as it is a low cost solution for educational settings and is adequate for using with classroom size groups, its benefits can be easily exploited by other higher degree institutions as an enhancement to traditional DG classes.

It is worthwhile to note that it was not identified in the research literature (or in the commercial market) any other similar solution, making the public availability of this application an important contribution to Descriptive Geometry education. All the other reported research which investigated some kind of virtual reality supported geometry teaching are not fit for using with large groups. One of these uses Augmented Reality (AR) techniques [3, 4]. That system has a very limited area for visualization and interaction and only users next to it can visualize the geometrical constructions executed. Besides that, the employed technology (AR) still demands high cost devices like see-through glasses, making its use unaffordable for groups of tens of students.
2 Virtual Reality and Spatial Abilities

Each day it becomes more common to find virtual reality components in computer systems used in a broad range of applications, consolidating VR as a promising technology. The expansion of applications based on VR is linked to the drop in prices of both hardware and software, together with an increase in their quality and performance. Today, VR can be considered one of the most advanced technologies for manipulation and highly interactive 3D control of computer models.

The technical literature presents a series of studies regarding the use and evaluation of VR in learning processes and cognitive and functional abilities rehabilitation. Foreman et al. [5] reported discoveries made from the study if several 3D environments supporting spatial orientation in brain disabled children. After exploring these environments, the patients achieved significant improvement in their spatial competences and were able to orient themselves in a real environment. Only children exposed to the 3D environment presented effective treatment effects.

VR applications can benefit people with cognitive and functional deficiencies due to traumatic brain damage, leading to neurologic dysfunctions and development and learning disabilities. Livingstone and Skelton [6] report on the several progresses they are achieving on their VR research investigating the use of virtual environments for evaluation and rehabilitation of cognitive and functional processes in individuals with central nervous system dysfunctions.

Ulrich et al. [7] describe some research on development of spatial ability in virtual environments, but identify an urgent need for more detailed research on this area. Those authors argue that training activities can improve spatial skills and, ideally, this kind of research should be interdisciplinary, exploring knowledge of different professionals (psychologists, engineers, computer scientists and educators). Also, on the research reported in [8], the gender differences of individuals navigating in a virtual environment were investigated.

In short, it can be verified the effective use of VR in situations which are difficult or impossible to realize in the real world [9, 10]. Therefore it is adequate to probe the use of VR for learning of abstract content like math and geometry and for developing students spatial abilities [11].

3 The DG@VR Software

DG@VR is an educational tool for supporting DG teaching that makes easy the creation of 3D geometric constructions that enhance visualization of spatial relationships and, consequently, learning of DG. In particular, this tool makes use if a VR technique - stereoscopy – to present the constructions with depth perception. Geometric scenes are created through interaction with the user (teacher). Figure 1 illustrates how the system is used in classroom.
4 Design of the 3D User Interface

4.1 Interaction device selection requirements

The application presented here has some fundamental requirements regarding design, development and application in an educational setting. The input devices must be low cost, easy to use and, one of them, fitted to 3D interaction. As textual input was also needed, the keyboard was the first device chosen, as it is universally available. To fulfill the 3D interaction need, the recently introduced Space Navigator was adopted. This table device is a fully functional 6-DOF with very low cost (Figure 2). Additionally, the mouse was also selected as a system’s input device because it is the easiest way for pointing elements on the screen.

Regarding output, device selection must consider how many users will view the system graphics at the same time as well as the desired effect (in this case, depth perception). Besides that, output components also need to be of moderate cost. All considered, the selected solution was a passive-stereo projection system. This solution uses two standard video projectors fitted with (linear or circular) polarizing filters and corresponding low-cost polarizing glasses. The use of a silver screen is needed to preserve light polarization and a dual-head graphics board is required to drive the pair of projectors. The main advantage of this solution is, besides its
low cost, the possibility of sharing the sensory experience with many users (all the students in a classroom).

4.2 Interface

The DG@VR interface has no menus or buttons, available in most traditional computer applications. Initially, only a pair of moonbeam planes appears on the screen (horizontal and vertical projection planes) which acts as a window to an infinite workspace. The system allows the exploration of descriptive geometry concepts and spatial constructions involving a moonbeam projection system, illustration of theorems and properties, presentation of the main elements (point, line and planes) of DG and special positions (Figure 3).

System interface is composed by the objects and functionalities 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**: 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 elements on the scene when explaining it to students.

- **Elements**: the geometric elements are points, lines and planes. Each element has its own representation. Creation of elements is done 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 other. When the system detects that the last selected element is near 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 frontal, top and isometric views.
• **Projections**: of points and lines are automatically shown in both projection planes when they are selected if commanded using the keyboard. Projection lines are shown dashed.

• **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 done by dragging the little arrows that appear on them whenever they are selected. Deletion of elements is done by selection and Delete key pressing.

• **Color and transparency**: the color of selected elements as well their transparency can be changed by pressing specific function keys.

• **Element labeling**: text keyed while an element is selected 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 file to be edited or created may be specified during start-up as a parameter in the command line. Saving is done by pressing a specific function key.

5 **Experiment Planning and Statistical Analysis**

After software development was completed, descriptive geometry classes were taught to students of the Escola Politécnica of the University of São Paulo (EPUSP) for evaluating the system. Three classes were selected to integrate the sample for the evaluation study and were classified as: control-group, stereo test-group and mono test-group. The control-group was given conventional DG classes, totaling 8 hours of instruction, without using the new tool. This allows measuring the spatial skill gain due to standard instruction. Students in the stereo test-group were exposed to the DG@VR system, with full functionality (stereoscopic projection) (see Figure 4). For the mono test-group, the same system was used, but not operating with stereo projection.

For measuring the students’ spatial skills, the TVZ (*Test de Visualização*) [12] was chosen. The standard testing time was reduced from 25 to 20 minutes and the score range was 0 to 18 points. The students took a pre-test in the week before the first DG class. Experimental classes run during four weeks, with a 2-hour class per week. Right after this period, students took a post-test for measuring their new TVZ scores and how much (and if) the developed system helped them to improve their spatial visualization skills. Also, the students answered a questionnaire for a qualitative evaluation of the system.

The study was conducted in the first semester of 2009. The study sample was composed by 91 students (75 men e 16 women), with 31 persons in the control-group, 29 in the mono test-group and 31 students in the stereo test-group.
6 Results

6.1 Quantitative Evaluation

All groups presented an increase in their spatial skill score as measured by TVZ. Figures 5, 6 and 7 show the performance of the three groups in the evaluations done in March (pre-test) and May (post-test), 2009. The horizontal axis is the TVZ score range. Statistics are shown in Table 1.

Figure 5 – Score increase of control group after DG classes.

Figure 6 – Score increase of mono test-group after DG classes.

Figure 7 – Score increase of stereo test-group after DG classes.

Table 1 – Statistics for the pre- and post-tests on the three groups.
TVZ (pre)  TVZ (post)  Gain

<table>
<thead>
<tr>
<th></th>
<th>Control group</th>
<th>MON test group</th>
<th>Stereo test group</th>
</tr>
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<tbody>
<tr>
<td>Potential range</td>
<td>0-18</td>
<td>0-18</td>
<td>0-18</td>
</tr>
<tr>
<td>Measured range</td>
<td>1-18</td>
<td>1-18</td>
<td>0-18</td>
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<tr>
<td>Average score (N*)</td>
<td>7.77 (31)</td>
<td>11.16 (31)</td>
<td>3.39 (31)</td>
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<td>Std. Deviation</td>
<td>4.93</td>
<td>5.76</td>
<td>3.42</td>
</tr>
<tr>
<td>KS (p-value)**</td>
<td>1.05 (0.220)</td>
<td>0.85 (0.454)</td>
<td>0.52 (0.950)</td>
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</tbody>
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<tr>
<td>Potential range</td>
<td>0-18</td>
<td>0-18</td>
<td>0-18</td>
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<tr>
<td>Measured range</td>
<td>0-18</td>
<td>2-18</td>
<td>0-18</td>
</tr>
<tr>
<td>Average score (N*)</td>
<td>8.31 (29)</td>
<td>12.28 (29)</td>
<td>3.97 (29)</td>
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<tr>
<td>Std. Deviation</td>
<td>5.25</td>
<td>6.02</td>
<td>3.98</td>
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<tr>
<td>KS (p-value)**</td>
<td>0.43 (0.991)</td>
<td>1.43 (0.033)</td>
<td>0.794 (0.554)</td>
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<tr>
<td>Measured range</td>
<td>0-18</td>
<td>0-18</td>
<td>0-18</td>
</tr>
<tr>
<td>Average score (N*)</td>
<td>6.68 (31)</td>
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<td>Std. Deviation</td>
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<tr>
<td>KS (p-value)**</td>
<td>0.81 (0.519)</td>
<td>0.68 (0.744)</td>
<td>0.684 (0.738)</td>
</tr>
</tbody>
</table>

Note: * N = Sample size   ** KS test

The differences on the average scores of the groups in pre- and post-tests were analyzed to check for significance using the student’s t-test for independent samples. According to the data, all three groups had a significant increase on their scores (p < 0.001). Next, the mono test-group score increase was compared for significance with the lower gain of the control group. The results, t = -0.604 and p = 0.548, lead us to reject the hypothesis of a significant better performance for the mono test-group gain compared to the control group. The same way, no significant differences could be detected between gains of stereo test-group and control group (t = -0.465, p = 0.644) or between stereo and mono test-groups (t = 0.161, p = 0.873).

6.2 Qualitative Evaluation

The first question of the qualitative evaluation regarded the efficacy in the visualization of the spatial scenes presented by the system. This question was only asked to students in the mono and stereo test-groups, the only ones exposed to the GD@VR system. All participants answered affirmatively to this question (100% of the sample). This data proves that the system fulfilled its role of exhibiting spatial scenes to students in classroom. The second question tried to identify any student discomfort when using the stereo glasses and, the third question, how often the glasses were used. The results showed that 87.10% of participants had no discomfort at all using the stereo glasses. The remaining reported some eye strain in some moments. Regarding question 3, only 16.13% (5 participants) reported not using the glasses all times for visualizing the stereo images presented. Those students argued that, in some occasions, they were able to understand the images even without the glasses and that the preferred not use them because they short sighted and the simultaneous use of both glasses caused some discomfort. As the number of students reporting discomfort was small, it is believed that it was not a cause for not detecting significance in the better performance of the system.

When answering if the stereo effect aided the visualization, 74.19% of participants responded affirmatively (totally + a lot) showing its use was very well accepted by students in the classroom (Figure 8).
The next question was about the understanding of pictures/animations presented. Most of the control group (48.39%) chose the “a lot” option. The presentation supported by the system operating in monoscopic mode was very well accepted by the mono test-group students whose major part (65.52%) opted for the “a lot” choice. For the stereo test-group the results were similar, with 51.61% responding they “a lot” understood the images. This result also shows the wide acceptance of the DG@VR system, promoting its use over the standard slides with parallel projection drawings. According to some participants, because they were not used to the two-dimensional representation used in DG, the system’s 3D animation, which enabled the visualization of the scene by different viewpoints, helped them a lot, promoting the use of the system as an interactive tool in the mono test-group.

The next question was about content learning, considering the tools used in classroom. The best result was obtained among the stereo test-group, with 51.61% of the participants opting for “a lot” and 25.81% for “totally”. The second best was the mono test-group, with 44.83% of the participants stating that they learned “a lot”. Among the students in the control group, 38.71% answered “a lot”. Once again, the results showed that the use of stereoscopy, according to students, is a good alternative to be explored in classroom, supporting course content learning. In the students’ opinion, the system helped them to visualize or to imagine the spatial scenes proposed in the exercises. However, they also pointed out that learning could have been easier if the system had been used more frequently in class. Regarding this last remark, it worth to note that the system was used as much as possible considering the present structure of the class, which was not changed from what it was before. Therefore, it is possible to improve DG@VR utilization if the organization of the class is changed for taking full advantage of the system. A restructuring could change the presentation of most slides, showing pre-constructed 3D scenes instead. The use of the system can also be incremented if the students could use it out of classroom, for instance, in the extra laboratory time today allotted for software training.

About the quality of the visual resources used in class, the approval of the users was detected. Overall, 74.19% of students in control group chose options “good” (51.61%) and “excellent” (22.58%). Results were even better for the mono and stereo test-groups. In the former, the approval index was 89.66% (65.52% “good” and 24.14% “excellent”) and, in the latter, 83.87% (64.52% “good” and 19.35% “excellent”).
7 Conclusions

The main objective and motivation for the development of the system described in this paper was to obtain a tool with a simple interface with no or little interference in the normal behavior of the teacher in classroom and that could take advantage of stereoscopy as a means for making easier the visualization of 3D geometrical scenes. Therefore, the solution included a six-degrees-of-freedom device providing the needed support for spatial geometric constructions, without much overload on the user.

An evaluation of the system with a sample divided in three groups was conducted. A control group had four traditional classes. A stereo test-group had the same classes but using the DG@VR system, in stereoscopic mode. The third test-group used the system in monoscopic mode. The results showed no significant difference among the three groups, before or after the experiments. A qualitative evaluation showed students approve the system, stating that the visualization of spatial scenes is improved with this use of DG@VR over the conventional slides.

Regardless of the technique used in class, it is known that the development of spatial abilities with DG classes is only achieved if the students practice the exercises themselves. It was verified that not always happen, as many students simply copy the exercises from colleagues instead of making them by themselves. This fact certainly has a detrimental effect on the acquired spatial skills during the course.

It is believed that external stronger factors than the technologies used in classroom influenced the results obtained. A new experimental design is being planned to further isolate the contributions of the stereoscopy for the development of the spatial ability as it is supposed it is efficient for improving understanding the spatial scenes, especially for very low visualizers. This new set up involves having students to make exercises in classroom with the system support.
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