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Work-in-Progress—Studying the Impact of the Virtual Course "Magnetic Field. Electromagnetic Induction" on Educational Results

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Abstract. This work-in-progress paper describes effect on spatial immersion in VR on educational outcomes based on the empirical research. Spatial immersion is one of the key features of immersive virtual reality, which qualitatively distinguishes it from the desktop virtual reality. The spatial relative position of objects and forces is crucial to understanding the laws and rules in physics studying. However, to what extent a better understanding of spatial laws would help in solving standard school problems has not been explored. The special software for the school education program module "Magnetic Field. Electromagnetic induction" for Vive Focus was developed to explore virtual reality learning as an additional tool to study spatial rules. A study was conducted with 61 ninth-grade students from five schools. The results have shown that learning in virtual reality has a positive effect on practical skills in the short term, while in the middle the effectiveness of VR was not revealed.

Keywords: Virtual Reality Education, K-12, Spatial Training, STEM.

1 Introduction

Modern digital technologies in physics and chemistry laboratory practice in Russian schools include demonstration and visualization of experiments, films, and presentations, which allow to fulfill typical needs of teachers: demonstration of experiments similar to real ones, visualization of hidden and invisible processes [1]. However, the use of such visualization tools does not contribute to the formation of spatial thinking, a significant component for STEM learning studied by Stieff & Uttal [3] and Ha & Fang [4]. A common place in the mentioned works is the following: spatial learning allows to "increase the level of retention, academic performance, and degree attainment remains outstanding" [2]. Being one of the most important properties of virtual reality, provides an immersive experience, which gives even more opportunities for the development of spatial thinking, since, in the artificially created three-dimensional world, students can change the point of view and zoom in and out of objects [5, 6].

Systematic reviews of AR and VR in STEM education show that these technologies can improve spatial thinking and problem-solving skills. Besides, they give insights that are difficult to gain in reality [7, 8]. One of the key examples of such type of research is a study by Carbonell & Bermejo [11] described the use of augmented reality to train engineers, which led to the development of spatial thinking.

However, educational results in connection with spatial thinking are controversial. There is evidence of effective use of VR in biology in terms of better test results and engagement level [9] and AR in mathematics, where the technology increased task-solving results [12]. In contrast, the study on electrical circuits showed no significant differences in spatial orientation or visual memory when using virtual reality simulators [10].

Studies on the introduction of virtual reality into physics have also examined the impact of such visualization on learning outcomes. An experiment to teach spatial thinking based on objects in virtual reality allowed students to manipulate tangible cardboard vectors [13]. The results showed a significant improvement in both their visual and spatial skills and their understanding of basic physical concepts. The same effect of increased understanding of spatial orientation was obtained by participants of another experiment that looked at introducing visualizations of mechanical systems into the educational process [14].

The aforementioned research develops spatial thinking through spatial visualization, but VR gives also immersiveness and embodiement Our hypothesis was that the spatial perception of physical processes and tasks through visualization and the use of bodily methods from traditional physics teaching methods will improve knowledge in the short to medium term.

2 Methodology

2.1 Sampling

Two groups (29 participants in the experimental group and 32 in the control group) were formed consisting of students who chose physics as an additional main state examination (MSE) in 2019 (in the Russian education system after the 9th grade four standardized exams are taken - two mandatory and two optional) to obtain a certificate of basic general education. These 9th grade students, 14-15 years old, from five educational institutions of Moscow and Vladivostok ("Phystech-Lyceum" of Natural Sciences and Mathematics named after P.L. Kapitza, Humanitarian and Economic College of FEFU, Choreographic School, University complex "Gymnasium-college" FEFU, FEFU Gymnasium) were divided into groups with an equal distribution of baseline achievement with an equivalent ratio of students from physics-oriented and general education schools. Due to the participation of minors, consent for participation and data processing was signed by parents.

2.2 Experimental Design

The research process was organized in the format of comparing the results of several control stages of the two groups. The experimental group had the following checkpoints: pre-test, virtual course, subjective learning assessment survey, post-test, and physics MSE exam. Students underwent an intensive blended learning course. The group watched the lesson or tried to solve the task and then discussed the results with each other using blackboard and under moderation, but without the instructor's explanation. The same procedure was repeated till the end of VR course elements. The control group took only the pre-test, post-test, and physics MSE. The control group attended their regular physics classes in a full-time format - frontal lectures with solving the tasks. The total training time was 4-4.5 hours, conducted over 2-3 days. Pre- and post-tests - identical tests with a modified order of questions, developed by Russian Academy of Education specialists - were taken within 3 days. The subjective evaluation questionnaire was designed to collect information on personal learning outcomes, compare with other formats, and assess individual characteristics of the virtual course. The results of the main state examination are presented in the protocol of verification format.

2.3 VR Course

A virtual reality course was developed to focus on the spatial characteristics of phenomena and learning spatial rules (Fleming's Left- and Right-Hand Thumb Rules). The course was developed using Unity platform for the Vive Focus autonomous device with 6 DoF design technology with the participation of physics teachers from St. Petersburg and Vladivostok. It is now available on-demand at FEFU, suitable for use on stationary platforms (PC VR), and on the Vive Focus and Focus +, whereas Pico Neo 3 and Quest 2 platforms will be supported in the near future. The visualizations present a virtual laboratory where physics experiments are conducted with additional animated drawings of processes, e.g., magnetic induction lines, electric current in wires. During lessons on "hand rules," hands with their respective positions and arrows describing the rules are visualized. The animation of the processes with explanations by the narrator is provided during the lecture. Fragments of images from the virtual course are shown in Figure 1.

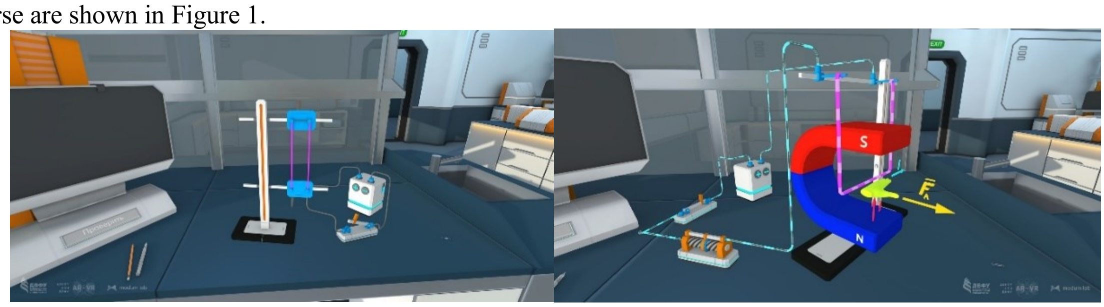

Fig. 1. Screenshots from VR course (the Ampere's force lesson).

The course includes 4 theoretical lessons (animation with offscreen voice), 5 practical exercises and solving 5 problems. It is focused on preparation for the MSE in physics, in particular on the solution of task #13, dedicated to magnetic and electromagnetic induction.

Theoretical classes consist of non-interactive animation and cover the following topics: 1- Permanent magnets, the Ampere's experiment, the Oersted's experiment; 2 - The Fleming's Left- and Right-Hand Thumb Rules for the solenoid; 3 - The Ampere's force, the left-hand rule and the Lorentz's force; 4 - The Faraday's experiment, the Lenz's rule.

Practical classes are interactive and immerse students into the physical experiment with a designated subtopic and the opportunity to take a theory prompt. After the practical task the student was given feedback on its completion. The practical classes included similar topics: Fleming's Right Hand Thumb Rule, Oersted's experiment, Fleming's Left Hand Thumb Rule, The Lorentz's force and Faraday's experiment.

Training tasks require placing arrows of current directions and forces correctly at the laboratory installation in virtual reality. These tasks are provided without any hints and repeat the topics of experiments in the practical part of the course.

3 Results

3.1 MSE Exam Results

The average final test score in the experimental group increased after VR-training, the average final score in the control group did not change. In general, the positive impact of VR-training on the test results can be seen. Figure 2 shows the test scores for both groups. Test scores improved by an average of 28.8%, or 1.22 points (with a maximum of 8 points).

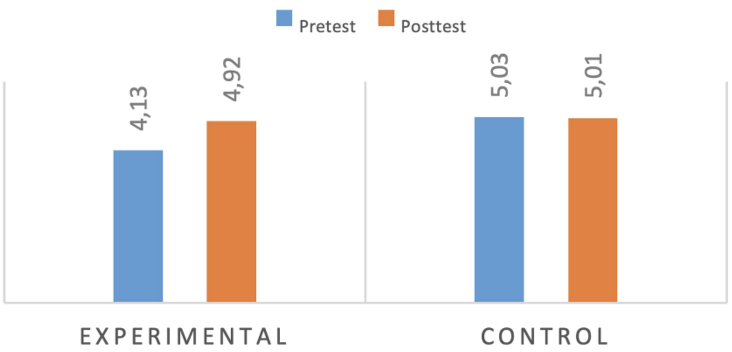

Fig. 2. Pre-test and post-test results.

Analysis of variance (ANOVA) suggests that deviations of the medians are significantly different (p-value < 0,1) which shows the impact of the virtual reality factor. At the same time, with a high level of trust, it can be argued that there was significant influence in the experimental group in Vladivostok compared to Moscow.

The total score obtained on the physics exam in the experimental group was on average 2.5 points higher than in the control group: (30.25 and 27.85, respectively), and the results of task 13 were the opposite: the average score in the experimental group was 0.61 points, and in the control group — 0.70. However, the effect of learning in VR on the overall results of the MSE or separately on task No. 13 using ANOVA was not identified (p-value > 0,1).

3.2 Results Based on a Previous Educational Performance

The distribution of students in both groups was based on the initial assessments in physics, which were obtained before the study: 50% students had above-average performance, 50% - below average. The comparison of their results of pre- and post-tests has shown that among the higher-scored half of the experimental group test results improved by 28.2% and the lower-scored half improved the test results by 46%. Additionally, the higher- and lower-scored parts were compared between the experimental and control groups according to the MSE results. The results of both halves of experimental group results were higher than the control group results by 11% in higher-scored halves and by 3% in lower-scored halves.

3.3 Group Results

In the Moscow group, the average score of the final test in the experimental group did not change due to VR-training. The average score of the exit test in the control group also did not change. However, when lowering the reliability requirement from 95% to 90%, then we can cautiously talk about the possible influence of VR-training can be seen. Thus, we cannot reliably state that there is an effect of VR-learning on the increase in the average test score, but the opposite cannot be stated completely either. There is no effect of VR-learning on the overall MSE score. There is no effect of VR-learning on 13th assignment in the MSE. The situation is different in the group from Vladivostok: the average score of the final test in the experimental group increased thanks to VR-training. At the same time, the average final score of the control group did not change. Overall, the positive impact of VR-training on the test results is shown. The test results improved by an average of 29.5%, or 1.27 points. There was no effect of VR training on the overall MSE score or on the 13th assignment in the MSE.

3.4 Questionnaire Results

The average score for improvement in practical task skills after the VR course was 8.61 (the maximum possible score was 10); The score is a subjective value provided by the students themselves. The theory development score was 8.28; and the NPS (proponent score) score was 8.94. Comments received by the students reflect positive feedback from those who received personally satisfactory results (translated into English by the authors): "Thanks to this project I stopped mixing up my left and right hands", "This experiment was very interesting and fascinating, I learned a lot of new things and got a lot of positive emotions".

Based on the comments from the users, the following areas of influence have been identified:

- Visualization of processes: "Everything is shown clearly - it helps with the understanding of the material"; "I liked that you can see everything more clearly than if you studied it in class"; "All the information was clear in contrast to the usual dry theory in physics lessons", "I liked to see each scheme in detail".
- Spatial representation: "Three-dimensional presentation of the material and interactive solving of tasks is amazing".
- Practice: "Visualization of actions. The opportunity to touch everything in the experiment".
- Individual work: "Full immersion in the studied material allowed us to master the topics".

Requests and suggestions for revision were identified:

- Creating the possibility of non-synchronous tasks solving by students of the same group;
- The ability to interact with virtual objects;
- Adding more tasks and topics;
- Adding the opportunity to solve the tasks together with other participants.

4 Conclusion and Outlook

At the moment, virtual reality is a developing technology that integrates into the educational process in order to enhance learning. In the current study it has been shown that learning in virtual reality has a positive effect on practical skills in the short term, while in the middle term the effectiveness of VR was not revealed. The development of research on the effect on the memory of information by students after the use of virtual reality for different periods of time is a prospect for future work. The influence of VR training on the results of the main state examination has not been reliably established, although the average result of passing the exam in the main group turned out to be higher. The possible reasons are:

- The sample number is not sufficient to obtain unambiguous results;
- ANOVA as a method does not give good data on the existing sample, it is necessary to test other tests e. g. the Wilcoxon test;
- The connection is indirect, the model needs more data on changing motivation, to see the connection clearly.

Based on the feedback from students, it was shown that VR provokes a positive reaction from the students. They rate this educational tool as valuable and are ready to recommend it to their peers.

Previously, virtual reality was seen as a full-fledged educational tool that allows students to master the material better and to motivate them. Since the pre- and post-tests and the MSE were aimed exclusively at application, the impact on the various levels of training remained hidden. In future studies, it is necessary to consider and distinguish the impact of learning in virtual reality on memorization, the ability to analyze the situation and apply knowledge in practice. To clarify the capabilities of VR, it is necessary to conduct research on a wider sample, as well as organize a comparative study with other tools in the short and long term.

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