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Virtual reality is more efficient in learning human heart anatomy especially for subjects with low baseline knowledge

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ABSTRACT

New technologies make their way into education and one of the most prominent of them is the immersive Virtual Reality (IVR). But the scientific data about its efficiency in the educational process is controversial. In the present study three randomized groups of students, who did not have biological and medical classes amongst their courses, studied human heart anatomy using three different learning methods – a paper (text and images); a 3D interactive human heart model presented on a computer display; an IVR human heart model. Prior and after learning session students performed the test of human heart anatomy with 28 open questions. The IVR group showed the increase of correct answers within the group and compared with other groups. Also, the subjects with lesser baseline knowledge in IVR group showed the greater increase of correct answers following IVR session. The structure and the way how the learning material should be presented in IVR and how it affects the learning outcomes are discussed.

1. Introduction

The development and implementation of new information and communication technologies gives rise to new forms of interaction between a computer and human, and one such form is Virtual Reality (VR). Virtual worlds generated using modern software and mediated through high-resolution head mounted displays (HMD), with stereo sound and ultra-precise tracking, create a very strong sense of presence (SoP) and immersion. Various virtual environments can be either representations of real places (for example, a virtual office space or a digital reconstruction of an ancient temple), or completely imagined, unrealistic with unique set of psychic laws (when the user is in a place inaccessible to him, like the surface of another planet or inside a molecule). The user can manipulate and interact with virtual objects, move inside the virtual space, verbally and non-verbally communicate with other users, create and play etc. In such environments the user is provided with a high degree of subjectivity (the ability of a person to act as a subject of action) and autonomy (Slater & Sanchez-Vives, 2016).

There is a distinction in literature between the desktop-based VR (DVR), mediated through a computer display and controlled with traditional keyboard/mouse inputs and the high-immersive VR (IVR), experienced through HMD and controllers with smooth and precise tracking. The rise of IVR has begun in 2016 with the commercial release of low-cost VR devices HTC Vive, Oculus Rift, Samsung VR and PlayStation VR. Unlike 10 years ago, when IVR systems were only available to limited number of researchers for tens of thousands dollars, now the high-immersive VR systems are easy to set up and use, they have intuitive controls and user-friendly software. Moreover, given the fact that any iPhone or Android smartphone can be used as an HMD, one may say that nowadays almost every person has own VR device at a hand.

1.1. VR common effects

Person's feelings and actions in various virtual environments depend on a number of technological and psychological features, the most important of which are immersion and sense of presence. Immersion is

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the property of a VR system that replaces or augments the stimuli to the participant's senses (Sherman and Craig, 2019; William R. et al., 2019). The degree of immersion is determined by the technological characteristics of VR medium, such as HMD resolution, frame rate, field of view, stereoscopy, stereo sound, tracking accuracy and speed etc. For instance, more photorealistic graphics in a virtual environment have a positive effect on immersion (Nalivaiko, Davis, Blackmore, Vakulin, & Nesbitt, 2015). Another factor is the magnitude of sensory stimulation - the effect of immersion is greater in the case of simultaneous stimulation of more sensory systems, congruence of stimulation of different modality and its intensity (Servotte et al., 2020). The sense of presence (SoP) is defined as the subjective experience of being in one place or environment, even when one is physically situated in another. There is a relation between immersion and sense of presence. Cummings and Bailenson (2015) have found that immersion has a medium-sized effect on presence. Additionally, they showed that increased levels of user-tracking, the use of stereoscopic visuals, and wider fields of view of visual displays are significantly more impactful than improvements to most other immersive system features, including quality of visual and auditory content.

The ability to freely navigate through VE and interact with virtual objects, when their physics is realistically modelled, greatly contributes to SoP (Hudson, Matson-Barkat, Pallamin, & Jegou, 2018; Jang, Vitale, Jyung, & Black, 2017). Stronger SoP is achieved when user embodies his or her virtual avatar, which realistically depicts user's movements with a help of motion capture technology (Schnack, Wright, & Holdershaw, 2019). It allows the person to perceive himself in the role of a subject of activity, rather than an outside observer during active involvement in the interaction with objects of VR. Personality traits of the individual, such as the ability to immerse in various contexts, the ability to ignore distractions, the feeling of "being captivated", the intensity of emotions provoked by content and the frequency of immersions into content (Witmer & Singer, 1998) also affect the strength of SoP.

Interactivity is an important aspect of VR, as it greatly contributes to the SoP. A number of definitions of interactivity have been proposed, but in the context of computer-based multimedia learning, interactivity is defined as reciprocal activity between a learner and a multimedia learning system, in which the [re]action of the learner is dependent upon the [re]- action of the system and vice versa (Domagk, Schwartz, & Plass, 2010).

1.2. VR in education

Due to described above effects, VR as a teaching method is mostly used in skill training. Manipulating with objects in VR significantly increases the efficiency of skill learning (Jang et al., 2017), especially the medical students' performance with surgical tools (da Cruz et al., 2016) and execution of technical skills (Jou & Wang, 2013). In a cluster analysis of the literature, which describes the trends in VR studies (Cipresso, Giglioli, Raya, & Riva, 2018), this field was the most studied, when knowledge acquisition and processing were less common, but from 2005 VR is also investigated in the context of school and high education (Lamb, Antonenko, Etopio, & Seccia, 2018; Rusiñol, Chazalon, & Diaz-Chito, 2018; Bouzar, Tandjaoui, Kadri, & Benachaiba, 2018; Yang, Zhang, Ji, Li, & He, 2019). Appearing in schools and universities as a 3D environment on a computer screen, interactive whiteboards and virtual worlds, games or simulations, VR increases the efficiency of learning process and at the same time corresponds to modern trends of technological development, adapting students to new conditions of life. At the same time, the use of new technologies makes it possible to expand the range of teaching methods, because VR brings visualization of objects as close as possible to real-world objects. Moreover, it simulates the environments which a person can not visit in real life due to various limitations. The education process is conducted in more efficient and interesting way - the novelty of the VR technology and the realism of recreated VR worlds induce positive emotions and user's interest during the learning session, which may be observed in successful learning task completion using VR (Merchant, Goetz, Cifuentes, Keeney-Kennicutt, & Davis, 2014). This is especially expressed when using game scenarios. (Virvou & Katsionis, 2008). Teenagers are always eager to try and to master something new.

Early studies has examined the use of VR in education, mainly focusing on the virtual worlds created by desktop PCs. The main conclusion was that virtual environments allow students to become familiar with abstract concepts (for example, the microcosm of bacteria) in specific ways (Winn, 1993). Later, this idea was developed (Dalgarno & Lee, 2009), who described features of educational 3D environments, such as expanding students' knowledge of spatial concepts; the ability to perform tasks that would be impractical or impossible to accomplish in the real world; providing opportunities for students to interact within a multiplayer virtual environment. The use of VR for scientific, technological and engineering training allows students to experiment with various systems, that cannot be changed in laboratory or industrial conditions, for example, the outer shell of the product or mechanism can be removed in order to show its internal structure and any changes in virtual environment can be easily reverted (Potkonjak et al., 2016).

These features of VR are more often being used in the educational process in recent time, but with controversial results. In many studies regarding using VR in education the positive effect was observed (Jou & Wang, 2013; da Cruz et al., 2016; Tüzün & Özdinç, 2016; Rusiñol et al., 2018) and this is also supported with meta-analysis (Merchant et al., 2014), where studies were classified as using traditional (lecture, textbook, paper-based exercise, 3D concrete models, or physical lab sessions), multimedia treatment (videos, graphics, or computer-based tutorials), combination (desktop-based virtual reality, traditional or multimedia methods) and no treatment in the control group. The meta-analysis shows that implementing DVR technology in K-12 program and higher education in forms of games, simulations and virtual worlds increases students' outcomes. Also, the studies differed on the learning outcomes measures for simulation, where studies assessing students' knowledge level were found to be more effective than the studies assessing skill level. Perhaps, this is because it may be easier to recall factual information, then to develop the skills in desktop-based virtual reality.

A recent meta-analysis (Concannon, Esmail, & Roduta Roberts, 2019) focused on how IVR was used in post-secondary level education and skill training, have found a positive outcome for high immersive VR delivered through HMD, after being compared with other platforms such as desktop display screen, 2D video, mobile phone, digital tablet or stereoscopic desktop display screen.

Recently, Meyer, Omdahl, and Makransky (2019) investigated the effect of pre-training in learning by using different types of media - 2D video and IVR through Samsung Gear VR HMD. The major empirical finding of this study is that the use of pre-training significantly increased knowledge and transfer in the IVR directly after the intervention, but it did not have a significant impact on learning or transfer in the 2D video condition. Also, the results indicate that pre-training significantly increases students' self-efficacy when learning in IVR, however this effect is not observed when learning through a video.

On the contrary, other study describes a negative effect on students' outcomes after presenting learning material in IVR, despite students' higher interest, motivation and engagement in the process (Parong & Mayer, 2018). The reason is the realism and complexity of virtual environment, which includes many moving objects, that distracts students' attention and reduces the learning outcomes. Authors suggest using more simplified virtual environments for higher outcomes.

In other study by Makransky, Terkildsen, and Mayer (2019) students learned from a science simulation via a desktop display (DVR) or a head-mounted display (IVR); the simulations of science laboratory contained on-screen text or on-screen text with narration. Across both text versions, students reported being more present in the VR condition; but they learned less, and had significantly higher cognitive load based on the EEG measure. In spite of its motivating properties, learning science in IVR may overload and distract the learner (as reflected in EEG measures of cognitive load), resulting in less opportunity to build learning outcomes (as reflected in poorer learning outcome test performance). Authors explained the negative results of learning that rather than reading and listening to the same text, some students (specifically in the IVR condition) simply listened to the narration without reading the text. Also, the added text competes with the graphics for limited visual processing capacity, and the learner wastes time trying to reconcile the two streams of information.

Many models have been proposed to explain the effects of learning in psychology and pedagogy. The most relevant theory in the context of this work is the theory of multimedia learning (Mayer, 2014). It is based on the assumption that a person has different systems for processing audial and visual information and each channel has limited bandwidth. Learning involves cognitive processes that create connections between these representations.

Also, The Integrated Model of Multimedia Interactivity, which consist of six components, was proposed (Domagk et al., 2010). The subject of learning activity is the *learner*, referred to personal characteristics, such as degree of prior knowledge and self-regulation, and affective traits such as self-efficacy and trait anxiety. The *learning environment* includes both the instructional design and the affordances of the learning system; *behavioral activities* describes what the learner does, physically, to interact with the learning system; *cognitive and metacognitive activities* are mental operations, procedures and processes which the learner performs in order to select, mentally integrate, organize and integrate new information into a coherent knowledge structure; *emotional and motivational states* are conditions of the learner that arise from the given situation. The result of the learning activity is the *mental model* which is used to refer to both the existing knowledge structures, and the gained knowledge.

Inconsistency of the results of the considered papers indicates the need for additional investigations. In the current study we studied the effect of presenting learning material in different ways on the learning efficiency of the human heart functional anatomy. Three ways of presenting learning material were chosen: a paper with text and pictures; an interactive 3D model of the heart on a computer screen; an IVR application.

2. Materials and methods

2.1. Participants

The subjects were 45 undergraduate and graduate humanitarian students from the Far East Federal University (mean age 21 ± 1,5 years) who did not have biological and medical subjects amongst their courses. Subjects have no neurological or mental abnormalities according to the self-report. They did not consume alcohol 24 h before the study and tonic beverages three hours before the study. All subjects were volunteers, older than 18 years old and signed an informed consent.

Subjects' previous experience of IVR was identified by a questionnaire. Majority of the subjects (60%) indicated that they did not use IVR or used it extremely rarely (from one to three times), 16.6% indicated that they used IVR rarely (up to five times). 23.4% indicated that they experienced more than five times, but no more than ten times. All subjects indicated that their IVR experience had been six months ago or earlier. Also, all the subjects used IVR for entertainment (playing games or watching video), none of them had any experience of using IVR for learning.

The subjects were randomly allocated to two control and one experimental groups. The first control group studied the material with three A4 sheets, each containing picture of the heart and educational text (Paper group); the second control group studied a similar educational text presented on a PC display while simultaneously viewing an interactive 3D model of the heart (DVR group); the experimental group studied educational material using high-immersive VR HMD (IVR group). Groups did not differ by age (Paper: 21.2 ± 2.3 years; DVR: 22.9 ± 3.5 years; IVR: 22.7 ± 3.6 years; $F(2.42) = 1.32$, $p = 0.279$, all pairwise differences between groups were $p > 0.436$, Bonferroni test). The number of male participants also did not differ between groups. (Paper: N = 9; DVR: N = 8; IVR: N = 9).

2.2. Learning methods

Paper group was presented with learning material from the textbook on normal human anatomy for medical students (Gaivoronsky & Vasilievich, 2014). The material was divided into three blocks and each block was presented on a separate A4 sheet with a picture of a 3D human heart model (screenshot from Sharecare VR application) with the numbered callouts, denoting the terms of heart structures on the left, and supplementing text on the right. The first page contained the picture of a heart and was titled "Heart anatomy". The supplementing text consisted of 159 words and 9 terms to learn: right atrium, right atrial appendage, right ventricle, left atrium, left atrial appendage, epicardial adipose tissue, left ventricle, apex of heart, heart base. The second page was titled "Heart and its blood vessels" and included a picture of lengthwise section of a heart. The text on the page was 96 words long and had 10 terms to learn: cavity of the right atrium, cavity of the right ventricle, tricuspid valve, aorta, left ventricle of the heart, aortic valve, cavity of the left atrium, left ventricle, atrioventricular or mitral valve, septum. The last page was titled "Circulatory blood vessels", and all the parts of the heart on the picture were semi-transparent, except for the blood vessels. There were 174 words text with 9 terms to learn: ascending aorta, descending aorta, brachiocephalic trunk, left common carotid artery, left subclavian artery, big vein of heart, the smallest veins, right and left pulmonary arteries, pulmonary veins.

DVR group was presented with an interactive 3D model of the heart on a 24" LCD monitor with frequency 60 Hz and 1920 × 1080 resolution. The 3D Organon Anatomy (https://store.steampowered.com/app/583620/3D_Organon_Anatomy/) application allowed subjects to rotate the model for viewing its external and internal structure from all sides. Accompanying text was shown on the screen.

In the experimental IVR group, the VR application Sharecare VR (https://store.steampowered.com/app/730360/Sharecare_VR/) was used. It allows the subject to move freely in the virtual environment and explore the anatomically accurate 3D model of the human body, its organs and their natural functions.

2.3. Apparatus

For comfortable use of VR HMD, we used a computer with an Intel Core i7-7700 CPU, 16 GB RAM, and an NVIDIA Geforce GTX 1080 GPU with 8 GB memory. These specifications are recommended for use with the HTC Vive VR HMD with an AMOLED display with frequency 90 Hz, resolution 2160 × 1200 dpi (1080 × 1200 dpi per eye) and viewing angle 110°. The HMD allowed adjustment of the focus and interpupillary distance, and was equipped with positioning sensors (accelerometer, gyroscope, magnetometer) and laser tracking with two external base stations. Two HTC Vive controllers were used for interacting and navigation. The sound was reproduced through the speakers.

2.4. Knowledge test

Learning efficiency was tested with the questionnaire containing 28 open questions related to the 28 terms defined in the learning material. The questions were divided into three blocks and each block was presented on a separate A4 sheet with a picture of a 3D human heart model with the numbered callouts on the left, and nine numbered blank spaces on the right. In other words, the questionnaire was identical to learning material for Paper group, except for the supplementing text, which was replaced with numbered empty fields. Participants had to write down by hand the terms, corresponding to the numbers on the picture.

2.5. Procedure

Upon arrival at the laboratory, subjects completed an informed consent and the test of their baseline knowledge of the heart (28 questions as specified in section *2.2. Learning methods)*. Then a 15-min learning session took place for different groups using three different learning modes. The learning materials for Paper and DVR groups were identical in content, however, in IVR group the corresponding text was replaced by text cues on the interactive 3D model of a heart. Immediately after completion the learning session, the subjects completed the test of their knowledge of the heart (same 28 questions) again. The scoring criteria was the match between the answer and the learned term.

2.6. Statistical analysis

The number of correct answers prior and post learning session, expressed as a percentage of the total number of questions, were calculated. Statistical data processing was performed using repeated measures analysis of variance. The between individual factor was the three groups of subjects (Paper, DVR, IVR) and the within individual factor was the two time points (pre-versus post educational session).

Evaluation of differences in mean values between the groups was done using Student's t-test for independent samples. To assess the statistical significance of the differences in the mean values of the test before and after the learning session within groups, the Student's paired *t*-test was used. Sphericity was controlled with the help of the Greenhouse-Geisser criterion, the magnitude of the effect was estimated using eta partial in the square, and post-hoc differences were calculated using the Bonferroni test. Correlation analysis was performed using a linear Pearson correlation coefficient, the significance level p was 0.05.

All statistical analyses were performed in STATISTICA 10 software.

3. Results

The number of correct answers (in absolute values and as a percentage of the total number of questions) of knowledge test before and after the learning session is shown in Table 1.

The repeated measures ANOVA of the percentage values showed a non-significant main effects of groups ($F(2, 42) = 2.23$, $p = 0.120$, $\eta_p^2 = 0.096$), and a significant main effect of time ($F(1, 42) = 55.86$, $p < 0.001$, $\eta_p^2 = 0.571$) and group × time interaction ($F(2, 42) = 63.95$, $p < 0.001$, $\eta_p^2 = 0.753$). To clarify this effect, we conducted individual ANOVA to the data before and after the learning sessions separately. At the baseline the groups did not differ from each other in the percentage of correct answers ($F(2, 42) = 0.67$, $p = 0.516$, $\eta_p^2 = 0.031$). Following the learning session, the group effect was significant ($F(2, 42) = 14.81$, $p < 0.001$, $\eta_p^2 = 0.414$), indicating that the two control groups did not differ from each other ($t(28) = 1.27$, $p = 0.565$), and in the IVR group the percentage of correct answers was significantly higher (Paper vs IVR: $t(28) = 3.95$, $p = 0.001$; DVR vs IVR: $t(28) = 5.50$, $p < 0.001$).

Within-group comparisons showed that in control groups the number of correct answers did not change from the pre-to post learning session (Paper: $t(15) = 2.32$, $p = 0.036$; DVR: $t(15) = -1.93$, $p = 0.074$, $p = 0.017$ with Bonferroni correction). In the IVR group, the number of correct answers significantly increased post learning session compared with the pre learning session ($t(15) = 10.34$, $p < 0.001$).

Next, we calculated the individual difference of the percent correct answers at the post learning session relative to the pre learning session. The number of correct answers increased by 2.62 ± 4.37% for Paper group and decreased by 3.33 ± 6.68% for DVR group, and it significantly differs from each other ($t(28) = 2.89$, $p = 0.007$). In the IVR group, the number of correct answers increased by 23.81 ± 8.92% and significantly differed from the both control groups (VR vs Paper: $t(28) = 8.26$, $p < 0.001$; IVR vs DVR: $t(28) = 9.43$, $p < 0.001$).

In summary, these results indicate that IVR is more efficient for studying novel information than the traditional methods such as reading of textual material or studying an interactive 3D model on a computer monitor.

The next question concerns the role of the basic level of knowledge on learning in our experimental setup. For this purpose, we calculated the correlation between the percent of correct answers at the pre- and post learning session (Fig. 1A) and found, that it was significant in all groups (Paper: $r = 0.94$, $p < 0.001$; DVR: $r = 0.85$, $p < 0.001$; IVR: $r = 0.70$, $p = 0.003$). Thus, the number of correct answers follow the learning session depends on the basic level of knowledge.

We also calculated at the correlations between the pre learning session performance of knowledge test and learning gain (test results post minus pre learning session) obtained follow the learning session in each group. These correlations indicate the individual percentage increase in knowledge depending on the baseline level. The correlation was insignificant in the control groups (Paper: $r = -0.22$, $p = 0.422$; DVR: $r = -0.36$, $p = 0.188$), but in the IVR group it was significant ($r = -0.58$, $p = 0.024$, Fig. 1B). In indicates, that the number of correct answers follow a virtual reality learning session increased more in the subjects with a low initial knowledge level.

Table 1
Mean and Standard Deviation of absolute number and percentage of correct answers pre and post learning session in groups of subjects with Papert, DVR and IVR material presentation.

	Pre learning session			Post learning session		
	n	%	CI, %	n	%	CI, %
Paper Group	14.3 (3.6)	51 (12.9)	43.8–58.1	15 (3.6)	53.4 (12.7)	46.5–60.6
DVR Group	14.3 (3.5)	51.2 (12.6)	44.2–58.2	13.4 (3.4)	48.3 (11.7)	41.2–54.5
IVR Group	13 (3.5)	46.5 (12.4)	39.6–53.3	19.7 (2.9)	70.2 (10.3)	64.6–75.9

Notes. n - mean absolute number of correct answers, % - mean percent of correct answers, Paper Group - group of participants with text and pictures learning material, DVR Group - group of participants with presentation of learning material using interactive 3D images on a screen, IVR Group - group of participants with IVR presentation of learning material.

4. Discussion

In the present study, we investigated the effect of various forms of learning material presentation (Paper, DVR and IVR) on the efficiency of its reproduction. Two main results were obtained. Firstly, the use of IVR in the experimental group produced a significant increase in knowledge in comparison with the other two groups. Secondly, the increase in the number of correct answers in the IVR group was greater for subjects who had a lower level of knowledge at pre learning session.

The results of the study indicate that, prior to the learning sessions, the groups of subjects did not differ in the amount of baseline knowledge. For all groups of subjects the number of correct answers was at the level of 50%, which indicates that test did not the biased to easy or complicated questions about the heart anatomy and physiology.

Follow reading the material in Paper group, the number of correct answers remains at the same level, that is, this learning method in the current experiment did not provide additional information about the cardiovascular system in adult subjects. We assume that these results are due to the low motivation of subjects to obtain knowledge that does not match their training profile, as well as the difficulty in mastering new terminology without having substantial knowledge in this area.

For DVR group follow the educational session the number of correct answers also did not change and remained at the same level as at baseline. Moreover, a comparison of the relative values of learning success before and follow learning session showed, that using 3D model of the human heart on computer screen produce negative dynamics in correct answers compared with the text reading group of subjects.

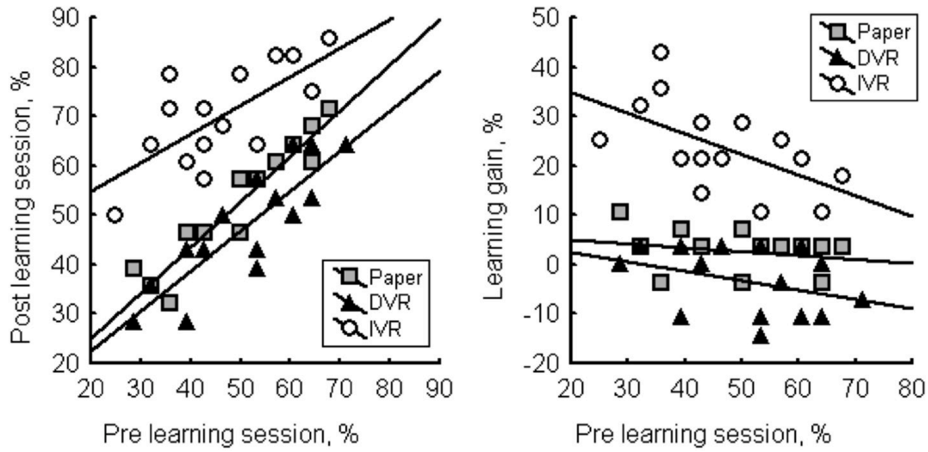

Fig. 1. Correlation between the performance of knowledge test in pre- and post learning sessions. A. Scatter plot of correlations between the number of correct answers of the knowledge test in percent at the pre- and post learning sessions. B. Scatter plot of correlation between the number of correct answers of the knowledge test in percent at the pre-learning session and learning gain obtained in post learning session.

Perhaps, negative results was due to the differences between the structures of learning session for text and interactive 3D model groups. In the former group subjects have to simply read the text and create the mental representation of the human heart anatomy. In the later group subjects had a more complex task of creating a mental representation of the cardiovascular system and comparing it with the 3D model on the screen. This requires the use of additional cognitive operations, reduces the focus of attention and the working memory performance. According to the Cognitive Theory of Multimedia Learning (Mayer, 2014) there are two separate channels (auditory and visual) for processing information and each channel has a limited (finite) capacity. In the current study competition of information took place in a visual channel only for Text and 3D condition.

It is interesting to mention, that the testing effect, which is expressed in producing the answer before the learning session, was expected to be observed in control groups, because the participants filled the same test before and after the learning session. However, the Paper group have shown no difference in number of correct answers past learning session in comparison with pretest, and the DVR group even have shown a negative dynamic. Thus, we conclude that testing effect was not found.

On the contrary to control groups, the use of IVR leads to a significant increase in the number of correct answers in comparison with the baseline. Therefore, 3D models of the heart and vascular system, presented in the IVR environment, have a positive effect on creating of a holistic mental image of this physiological system. These results correspond to meta-analysis data (Concannon et al., 2019), that points on the positive impact of using IVR in higher education.

Our results also in contrast with the other researches (Makransky et al., 2019; Parong & Mayer, 2018), that showed negative effects of 3D images on learning outcomes. In these studies the task was structured in the way that subjects' visual channel was overloaded with lots of distracting objects, not related to the learning material. Parong and Mayer (2018) argue that objects with multiple dimensions are distracting due to the difficulty of identifying meaningful dimension, and segmentation of the educational process contributes to more effective learning using IVR. However, the virtual environment in their study was significantly different from the one in current study. The subjects in Parong and Mayer (2018) experiment traveled in the cockpit through arteries while being distracted by blood bodies. Thus, the virtual environment was in constant motion and was filled with a variety of objects that divert subject's attention from the main task. In our study, the virtual environment was static, the virtual object in the form of a heart did not change its location, and the heart contraction process had been repeating cyclically, allowing the subject to examine it in detail and from different perspectives. Thus, the effectiveness of using IVR depends on the characteristics of the environment presented to the subject. Another difference is the ability of the subjects to be active during VR exposure. In the Parong and Mayer (2018) experiment, the subjects were in the cockpit and had limited ability to control their movement. According to (Jang et al., 2017; da Cruz et al., 2016; Jou & Wang, 2013), active movement and the object control in VR greatly contributes to the learning outcomes, by increasing subject's SoP and motivation. In contrary to Parong and Mayer (2018), in the present study, subjects could walk around the virtual heart, view it from different angles and actively manipulate with it by rotating, zooming, making sections, playing animations etc.

In study by Makransky et al. (2019) the virtual chemical laboratory was used and the design of VE was similar to the current experiment. However, subjects in Makransky et al. (2019) had to divide attention between text and VE, which led to more cognitive load and, as a result, to lesser gained knowledge. On the contrary, in the current experiment the text was given in form of cueing tips and it helped the students in creating a holistic metal representation of the heart anatomy and physiology, expressed in increased learning outcomes.

Our results demonstrate the advantage of IVR compared to more traditional methods of reading text material and using interactive 3D models on a computer screen in learning efficiency. Perhaps, this advantage is based on the holistic, dynamic form of the material presentation. The IVR allows subjects to immediately recognize the connections between object's features and memorize the entire system involuntarily. But these advantages of IVR are significantly affected by the structure and organization of learning material in VE. Contrary, subjects in text group have to connect the main points of the abstract material with voluntary control, which requires greater cognitive effort and time for its comprehension and acquisition.

The second part of the results concerns the influence of the baseline knowledge on learning gain. As a result of reading text and using of 3D models, the level of knowledge did not change. On the correlation scatterplot the knowledge test results pre versus post learning sessions are located along a diagonal line with small deviations. In the IVR group, the situation is different - subjects with low baseline knowledge had higher scores in the test follow IVR learning session. In contrast, subjects with higher pre session knowledge showed a smaller increase in the test follow VR session. Correlation analysis of the learning gain and the baseline knowledge results showed the negative relationship in the IVR group, which was not observed in the Text and 3D model groups. Perhaps, subjects with a higher basic level of knowledge have a ceiling effect, manifested in a smaller increase in the number of correct answers follow the learning session.

Limitations in this research should be noted. Due to its novelty for the participants, IVR attracts more attention and may have an impact on the motivation of the subjects, which may affect the higher success of the tests follow the application of this method. The novelty effect of new technologies for learning was noted by Southgate et al. (2019) and subjects themselves recognized this effect. Also, it is interesting to note, that most the subjects were involved in collaborative activity even when they were not undertaking the learning task. This suggests that the embodied sociality of multi-user IVR could be harnessed for effective learning. However, in our study there was no opportunity for collaboration among the subjects, and this is a prominent topic for future research.

Also, interactive 3D model and IVR groups interacted with different software applications (3D Organon Anatomy and Sharecare VR respectively), although the 3D models of the human heart in both applications were almost identical.

5. Conclusions

Studying in the IVR environment was found to be more efficient, than reading texts or interacting with a 3D model on a computer screen. The greatest knowledge gain was observed in subjects with the relatively low baseline level of the relevant knowledge. These results justify recommendations for implementation of IVR in education, but the design of VE, it's dynamic parameters and objects, that divert the subject attention from studied object should be taken into consideration. Also, the use of IVR in teaching might be more efficient in the initial stages of education and for students who find it difficult to master the material through traditional ways of studying.

CRediT authorship contribution statement

Y.P. Zinchenko: Supervision. **P.P. Khoroshikh:** Data curation, Writing - original draft, Software, Validation. **A.A. Sergievich:** Visualization, Investigation. **A.S. Smirnov:** Visualization, Investigation. **A.V. Tumyalis:** Conceptualization, Methodology. **A.I. Kovalev:** Data curation, Writing - original draft. **S.A. Gutnikov:** Writing - review & editing. **K.S. Golokhvast:** Conceptualization, Methodology, Supervision.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.newideapsych.2020.100786.

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