Virtual Reality Applications in STEM Education

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Abstract—**Efficient learning process in the area of science, technology, engineering and mathematics depends on many factors. Motivation of students to learn is one of them and requires deployment of attractive learning objects which can captivate students' attention, involve them in solving problems and connect their experience with knowledge. Virtual reality applications represent modern technology which could offer new possibilities and meet these requirements. In this paper we present two virtual reality applications (games) we developed within international project Newton. These applications were included in pilot testing at a secondary school. Results from research study showed increased motivation of students to learn and positive knowledge gain.**

I. INTRODUCTION

During last decades a lot of research has been done to design, implement and analyze new pedagogical approaches to improve a learning process efficiency and more captivate learners' attention. Various applications of self-directed learning (that belongs to student-centered learning) have been proposed such as problem-based learning [1], game-based learning [2], flipped classrooms, computer supported collaborative learning or inquiry and project-based learning [3].

There is still high demand for students who achieve required level of proficiency in the area of science, technology, engineering, and mathematics (STEM) [4]. Unfortunately, a lot of students are not motivated to learn STEM topics and new learning methods and approaches have to be implemented into e.g. secondary or high school education. Technology enhanced learning (TEL) is an approach that could positively influence that problem and above mentioned self-directed learning concepts integrated with state-of-the-art technologies such as virtual reality (VR) and augmented reality (AR) applications, virtual or real labs, and mulsemedia applications could bring new dimensions in this domain.

Since students should learn from their experience when they are actively involved in solving problems, virtual reality applications (e.g. games) have a potential to significantly support students' motivation to learn and even to improve their social, collaborative and cognitive skills [5]. However, it is necessary to realize a lot of research in this domain to fully uncover benefits as well as limits of VR technologies at a level of all types of schools including students with various disabilities.

The paper is organized as follows. Section 2 presents a short overview of current situation about VR applications. Section 3 introduces two VR applications (games) developed within Newton project. Proposed and implemented research methodology of the case study and results we achieved are presented in Section 4. Section 5 concludes this paper and summarizes some findings and future plans.

II. RELATED WORK

At present time there are a lot of various virtual reality applications which were developed and intended for various purposes such as entertainment via games (e.g. Allumette, End Space, EVE: Gunjack, Skylight, Minecraft, etc.), tools for artists (e.g. Tilt Brush, CoolPaintVR, Gravity Sketch, Kingspray Graffiti Simulator), flight simulators in an imaginary world (Sky Fighter) but also in a real world (Google Earth), documentaries (Aftershock VR, Ocean Rift, Discovery VR), players of TV (Netflix, Littlstar), shows (The foo Show), sport events (SportsCenter) and videos, desktop tools (Virtual Desktop) and many other demos and tools (e.g. in hospitals).

Another domain where VR applications gradually appear is represented by VR applications suitable for educational deployment [6]. Besides already mentioned flight simulators in a real world or documentaries users can discover the universe (Star Chart, Titans of Space, Victory VR: Adventures in Space, Merge Cube), analyze climate change (Cleanopolis), visit museums (Boulevard) and sites (Sites in VR, Google Expeditions), study a history (Universiv, King Tut VR) and the human body (Anatomy 4D), help in languages (Google Translate) and words (Flashcards Animal Alphabet).

It can be seen that application of VR in education mainly relates to medical, biology, science, history, social, geography and language topics. Unfortunately, information and communication technology (ICT) topics which are taught at secondary and high schools and universities are not represented yet by existing VR applications and research studies. We can only mention a VRFiWall application developed and presented by authors in [7] and destined to educating the Firewall concept as an important component of network security. This VR application is intended for students of universities to support lecture based classes.

Authors in [8] presented an application for mixed reality visualization (3D printed physical objects and Augmented Reality simulation) that is suitable for teaching complex multi-step problems in computer networking.

III. VR APPLICATIONS

In order to introduce new technologies in the classrooms and education two VR applications (games) –

Figure 1 "TCP-IP Protocol stack" game

TCP/IP Protocol Stack and Firewall – have been incorporated in self-directed learning. These games are described in following subsections.

Hardware equipment that is necessary to see and play these games includes a smartphone (e.g. Samsung Galaxy S7 was used in our case) where particular VR applications are installed. The VR games are controlled by a gamepad (e.g. Xbox One Wireless Controller) which is wirelessly connected to a smartphone with a VR application. The last component needed to fully feel a virtual reality is a mobile VR headset (we used VR Box 2.0) in which the smartphone with VR applications is inserted.

A. TCP/IP Protocol Stack Game

TCP/IP Protocol Stack VR application helps students to learn a protocol stack and a set of selected network protocols situated in it. Student can easily memorize what protocols belong to what stack layer (Table 1).

The main scenario of this game is based on balloons that represent particular protocols. Balloons fly up across four TCP layers. Student must hit a protocol balloon at the right protocol layer using a weapon (see Fig. 1).

This game consists of a number of levels that are divided into five basic protocol families (internet, mail, IPTV, support services, multimedia). Each family contains a specific stack of protocols that will be used in the game. The student can be focused on any protocol family. Game starts after selecting a family. At the beginning a player sees a TCP/IP protocol stack in front of him. The player is holding a weapon that will be used for shooting balloons. Each level has own parameters (speed, number of balloons, etc.).

TABLE I.
NETWORK PROTOCOLS AND LAYERS THEY BELONG TO FOR TCP-IP PROTOCOL STACK GAME

RM OSI	TCP/IP	Protocols
Application	Application	HTTP, DNS, FTP, DHCP, SSH, SOAP, RTP, SIP, RTCP, XMPP, Telnet, NETCONF, RIP, IS-IS, BGP, SMTP, POP3, IMAP
Presentation		
Session		
Transport	Transport	TCP, UDP, RSVP
Network	Internet	IPv4, IPv6, ARP, RARP, ICMP, ICMPv6, IGMP
Data Link	Network interface	Ethernet, 802.3x, 802.11 (WiFi)
Physical	(hardware)	

In some levels, balloons' color can respond to a color of layer to help students to learn faster new protocols. Some levels can contain grey balloons (not colored) for higher difficulty. If the player shoots a balloon at a right protocol layer, points are awarded as a reward. If the player shoots a balloon at incorrect protocol layer, additional balloons are generated and the player is penalized. Player passes through all levels and collects points.

B. Firewall Game

Firewall VR game helps students to understand in depth how a firewall and firewall rules work. It also illustrates the main principle of a decision process.

The player is a member of "Firewall", he is an ancient soldier that protects the kingdom against those who want to attack the castle in order to bring some illegal items onto its premises.

The player is inspecting freight in front of the gate (see Figure 2). When shipment passes the inspection, it may enter the castle. The player's main game area is the castle main gate. His main task is to inspect all freights, which are delivered into kingdom. Freight is carried by individual artificial intelligence controlled bots. Each of them is supposed to stop at player's base near the gate. There is the "inspection time". Player is given the list of forbidden items, which can be changed during the game. When a person stops in front of the gate, he or she has to show a list of items in his/her inventory. After inspecting the inventory list, the player decides whether to allow or not for that person to enter the castle with his freight.

A student / player must inspect not just items but also a number of houses (ports) where an item is sent. Game levels will provide various game modes. The easiest game mode is based on inspection of items that must belong to a specific rule. Second mode is based on items and numbers (ports) where each item represents a specific protocol sent to a specific port.

The main objective is to allow entering the castle for all items (protocols) with the right number (port) and destroy all illegal items.

Figure 2 "Firewall" game

IV. Case Study

This research study was realized in the framework of a large-scale EU Horizon 2020 project called Newton [9]. The main goals of the Newton project are development, integration, deployment and dissemination of state-of-the-art technology-enhanced teaching/learning methodologies (such as virtual/augmented reality, multimedia, mulsemedia, interconnected fabrication labs [10], virtual lab technologies [11], gamification and self-directed learning). The project addresses users (students) of primary schools, secondary and vocational schools, as well as high and university level of schools including students with physical disabilities. A new platform called NEWTELP was developed to manage learning process and disseminate learning content.

This paper mainly concentrates on students' knowledge acquisition when two new learning approaches are deployed in education of a STEM subject. Two virtual reality applications have been developed to teach selected subjects in Networking (computer networks) domain and incorporated in self-directed learning process with aim to investigate how a level of acquired knowledge is influenced in comparison with simplified self-directed learning process.

A. Research Methodology

As was already said, pedagogical approach we applied to increase learner quality of experience and to improve learning process was based on self-directed learning. Its adopted scheme in our lessons (modules) is depicted in Fig. 3. Before modules / lessons started we collected consent and assent forms, described students a research study and asked students to fill in special pre-questionnaires. Each lesson consisted of several components. To be able to investigate a level of knowledge acquisition by students they took a pre-test at the beginning of lessons as well as post-test at the end of lessons. In order to compare a benefit of our new pedagogical approach all students were divided in two groups. A group of learners who followed the learning process shown in Fig. 3 and tested new pedagogical approach was named as an experimental group (EG). The second group (referred to as a control group, CG) of learners took part in simplified version of self-directed learning. Basic difference in a structure of learning process between the experimental and control group is more clearly sketched in Fig. 4. Both groups took the same pre-test at the beginning and the same post-test at the end of each lesson. By comparing results of these tests a knowledge gain could be calculated and evaluated. Both groups of learners received study materials in electronic version to learn in their spare time. It can be seen based on the schemes in Fig. 3 and Fig. 4 that the experimental group received other learning objects. They could perform a several self-tests to test their actual knowledge. They also could work out a worksheet. Moreover, they took part in practical experiments at their school where they were

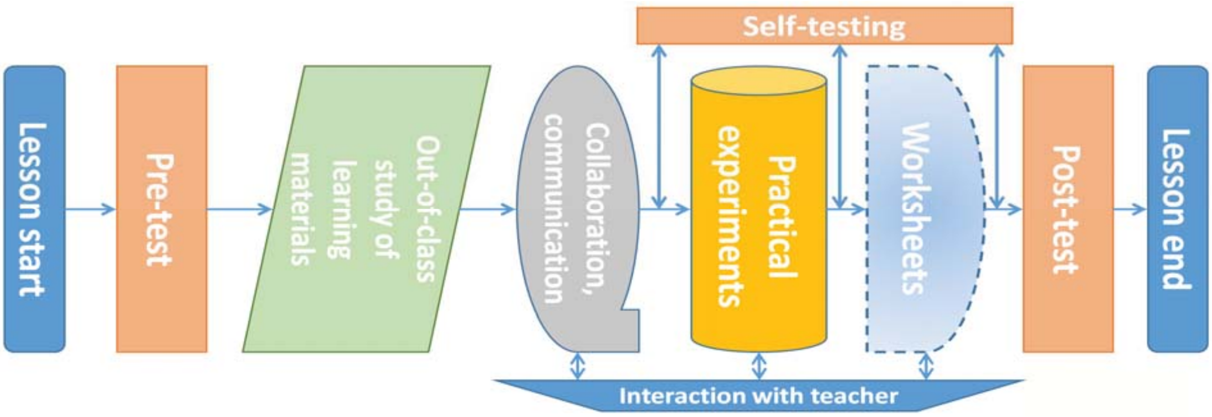

Figure 3 Adopted scheme of self-directed learning pedagogical method within our courses

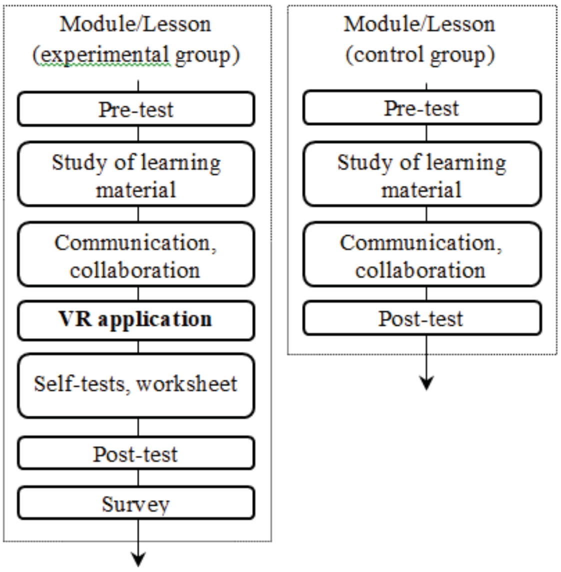

Figure 4 Comparison of learning process for an experimental and control group of students

able to try and play developed VR applications (games) and receive more information in a subject using new virtual reality technology. At the end of each lesson learners of the experimental group took a post-questionnaire to evaluate a learner satisfaction and impact of the new pedagogical approach on learners' learning experience. Representatives of the Newton project (pilot leader/local researcher, instructors) took part in practical experiments and introductory workshops with school teachers and students.

All learning components (objects) were disseminated via a new learning management platform developed by a project partner. Students received login credentials to access this platform and to take tests, download study materials and worksheets, communicate and fill in surveys.

As was mentioned both groups (EG and CG) took identical pre- and post-tests in both lessons to allow us to evaluate the knowledge acquisition. The pre- and post-tests development had to keep requirements:

- each test should last 10 minutes at most,
- both tests have to be similar in content and identical in the temporal extent.

In tests 7 single choice questions were included. Table II shows an example of the pre-test and post-test for Lesson 1 – RM OSI and TCP/IP Models.

The case (research) study described and evaluated in this paper has been realized at Vocational school of Information Technologies (SOS IT) in Banská Bystrica (Slovakia). Two standard classes of students at this school have been chosen as learners of Newton project pilot testing groups. The experimental group contained 23

TABLE II.
THE PRE-TEST AND POST-TEST QUESTIONS USED IN

Pre-test questions						
1. How many layers does the RM OSI model have?	2. What purpose is IPv4 class D reserved for?	3. How many bits does the IPv6 address have?	4. What does an IPv6 anycast address represent?	5. Which TCP / IP model layer does TCP work on?	6. What is the DNS protocol used for?	7. What is the SIP protocol used for?
a) 4	a) It is reserved for experimental use.	a) 16 bits	a) Any nearby server on the network.	a) on the network interface layer	a) authentication and encryption of packets	a) to monitor and manage devices in an IP network
b) 6	b) It is reserved for DNS servers.	b) 32 bits	b) It identifies the interface group; packets go physically to the nearest member.	b) on network layer	b) two-way interactive text-oriented communication	b) to exchange emails between e-mail servers
c) 7	c) It is reserved for government servers in the US.	c) 8 bits	c) It identifies the interfaces of the individual nodes.	c) on transport layer	c) to translate an IP address into a man's understandable name	c) exchange of structured reports
d) 5	d) It is reserved for multicast use.	d) 128 bits	d) It identifies the interface group; packets go to all members of the group.	d) on application layer	d) allows automated setting of TCP / IP parameters	d) to create, modify, and terminate multimedia sessions
Post-test questions						
1. How many layers does the TCP/IP model have?	2. What purpose is IPv4 class E reserved for?	3. How many bits does the IPv4 address have?	4. What are IPv6 addresses assigned to?	5. Which TCP / IP model layer does UDP work on?	6. Which protocol is used to build, modify, and end multimedia sessions?	7. What is DHCP used for?
a) 4	a) It is reserved for experimental use.	a) 16 bits	a) interfaces	a) on the network interface layer	a) DHCP	a) It identifies the interface group; packets go to the physically closest member.
b) 6	b) It is reserved for DNS servers.	b) 32 bits	b) nodes	b) on network layer	b) UDP	b) To create membership in a multicast group.
c) 7	c) It is reserved for government servers in the US.	c) 8 bits	c) ports	c) on transport layer	c) IPsec	c) To translate an IP address into a man's understandable name
d) 5	d) It is reserved for multicast use	d) 128 bits	d) applications	d) on application layer	d) SIP	d) It allows automated setting the TCP / IP parameters

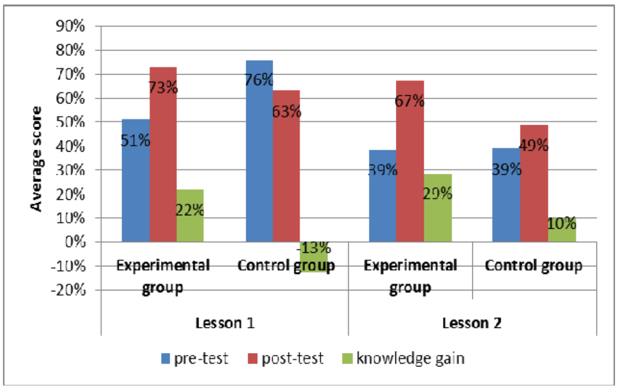

Figure 5 Average pre and post-test scores and the knowledge gain for Lesson 1 and 2

students and went through new pedagogical approach shown in Fig. 3. Another class of 29 students represented the control group. The practical experiments (learning with VR applications) took place during the normal hours of study at this school (under cooperation of school teachers and members of Slovak University of Technology).

B. Results Analysis

In this paper we analyze a knowledge acquisition as well as user satisfaction resulting from new pedagogical approaches based on self-directed learning and virtual reality applications. The learners' knowledge acquisition was evaluated based on results of pre- and post-tests taken by students of both groups (experimental and control). Learners' satisfaction was evaluated based on some results of surveys/questionnaires.

Fig. 5 shows a graph with results for an average score in percentage of pre-tests and post-tests for both lessons and both groups (EG and CG) of learners. At the same graph the level of acquired knowledge (referred to as the knowledge gain is depicted). In case of Lesson 1 a level of knowledge for taught topic (RM OSI and TCP/IP models) achieved value of 51% for the experimental group and 76% for the control group. It means that those groups didn't started with the same level of knowledge and learners of the control group were more experienced in that topic and were much ahead. However, when we compare post-test results for Lesson 1 it is possible to see that a level of knowledge achieved the value of 73% for students of EG and 63% for students of CG. It means that a level of knowledge increased in case of EG but decreased in case of CG. Based on results for Lesson 2 (Information and network security) we can see that students of both groups started with the same level of knowledge in that topic (39%) and it looks that students were not very familiar with that topic. From post-test results we can see that all students improved their knowledge but a level of improvement was higher in case of EG. We can summarize that students of EG improved a level of acquired knowledge in both lessons. On the other hand students of CG showed even decreased level of acquired knowledge after Lesson 1 and very small increase after Lesson 2. We can state that self-directed learning approach is not very suitable for students of secondary schools when they have to manage their own learning process. It is visible not only in case of students of the control group but as well as in case of the experimental group where the average scores of post-tests achieved values of 73% and 69%. Incorporation of VR applications, self-tests and worksheets in a self-learning process increased students' motivation to learn and help them to understand some topics better but there is still a place to improve and move on a level of acquired knowledge to higher values. Since each lesson contained only one VR application explaining a single part of entire topic the rest parts of a topic were mainly explained by study materials. In order to increase the knowledge gain it would be suitable to include more VR applications (games) for each topic (lesson).

In Fig. 6 there are percentages of correct answers for pre-test and post-test questions of Lesson 1 (shown in Table 2). It is possible to see that questions 2, 4 and 7 in the pre-test and a question number 4 in the post-test were the most difficult and because questions with the same number (in pre-test and post-test) are always very similar and from the same topic it is possible to identify a domain which is for students complicated and need to be (probably) explained in study materials more clearly. On the other hand when we analyze the graph with post-test questions it is easy to identify a question with highest percentage of correct answers (in EG). It is question 5 and it relates to a topic which was presented and taught by a VR application (game) developed for this module.

Learner satisfaction analysis was realized based on several instruments. As was already mentioned students completed usability questionnaires and during practical experiments the Newton project representatives have been

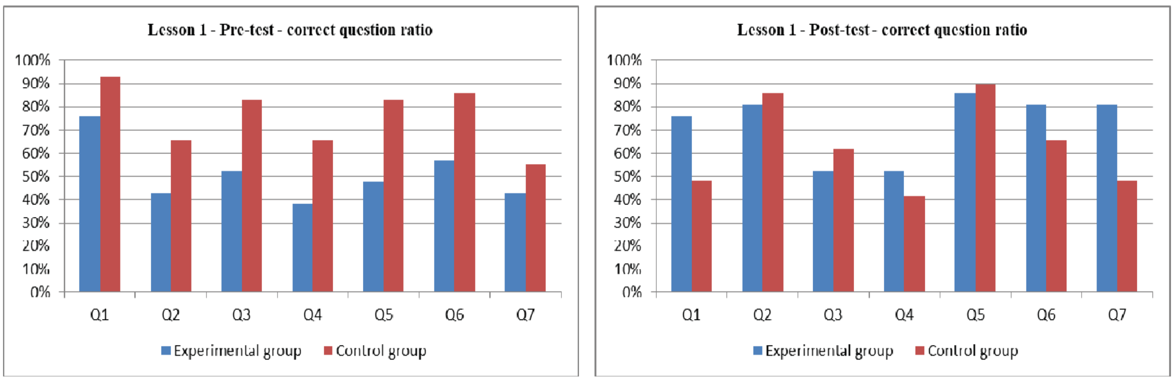

Figure 6 Percentage of correct answers for pre-test (left) and post-test (right) of Lesson 1

observing learners' behavior and comments. Moreover, after the learning process special interviews with learners (8 learners from the experimental group) and teachers were realized. Results on these activities showed that

- students were motivated to learn using new technologies such as virtual reality applications but there were some students who didn't feel comfortable to watch them via a VR headset,
- VR games helped students to understand learning topic better and would require more of them in learning process and games could be more difficult to complete,
- self-directed learning approach is still difficult for students of secondary schools and their learning activities need to be still managed by teachers,
- learners' satisfaction is very influenced by stability of all software and hardware components involved in learning process (e.g. learning management platform used in this pilot was in a testing phase and showed some occasional instability resulting in low learners' satisfaction with it),
- learners appreciate when learning is more active and visually augmented and VR applications brought new entertainment into practical classes,
- learners expressed that it was ease to learn how to use a project learning management platform as well as VR applications.

V. Conclusion

New technologies and new pedagogical approaches bring new challenges to the learning process. In this paper we analyzed two new learning technologies and their impact on students' level of knowledge acquisition as well as students' motivation and satisfaction with integrated technologies. Self-directed learning and two virtual reality applications have been integrated and then tested by students to investigate benefits and shortcomings of such learning approach. 52 students from a secondary school (in Slovakia) took part in this research study. They were separated into two groups (experimental and control) in order to compare and evaluate results for different learning approaches (self-directed learning with and without VR applications and other supportive learning objects) within two lessons oriented to networking topics.

Results of pre-tests and post-tests taken by students of both groups (at the beginning and end of lessons) allowed us to evaluate a percentage level of knowledge acquisition for both groups of students. Based on results we can conclude that students of the experimental group (when VR applications and other learning object were included in learning process) achieved a higher knowledge gain in both lessons against students of the control group. Achieved level of knowledge acquisition (based on post-tests) for students of the experimental groups achieved values of 73% and 69%. In order to increase these levels e.g. more VR applications/games should be included within one lesson.

Based on observations, questionnaires and interviews with pilot (course) participants (learners and teachers) we found out that the students were motivated to study because new technologies (VR applications) were included. They would like to have more such learning objects in practical classes and even more difficult to complete. However, self-directed learning approach in case of students of a secondary level of schools is still difficult pedagogical approach because students at this age don't have a lot of motivation for self-study and need teachers' supervision.

We would like to extend this research study in future and investigate how described learning approaches (self-directed learning and VR applications) influence learners' knowledge acquisition in case of high school and university students as well as students with physical disabilities.

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