

Teaching and Learning Physics using 3D Virtual Learning Environment: A Case Study of Combined Virtual Reality and Virtual Laboratory in Secondary School

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Abstract:

A common problem in many schools is the lack of equipment and materials in their science laboratories due to both limited budget available to the school and high maintenance cost of the lab. The latest technological advancements provide great opportunities for schools to go over the budget and cost issues by using 3D virtual learning environments that support simulations and observations of various experiments. A 3D immersive computer-based Physics educational application that teaches water cycle in nature and precipitation formation concepts through virtual reality and experimental virtual laboratory simulations was designed and developed as part of European Horizon 2020 NEWTON Project. The application was employed and evaluated as part of a case study carried out in a secondary school in Dublin, Ireland. 27 children of age 12-13 years old took part in the study as part of the experimental group. This paper presents an analysis of the user experience and usability results of the developed application, showing a high user experience score. The experimental group students also found the application enjoyable and they would like to take part in such novel-approach lessons more often.

Introduction

Science, Technology, Engineering, and Mathematics (STEM) subjects are currently exhibiting diminished interest from learners, especially after second level education. It is vital to improve their motivation and engagement in these subjects and encourage pursuit of third level STEM degrees, which are suffering with low university enrolment rates. This can be achieved by using Technology Enhanced Learning (TEL) and interactive solutions, which will engage students in the learning process, will motivate them and will improve their knowledge gain, subsequently removing the perception that STEM subjects are difficult and increasing their interest in STEM-related careers. Different technologies have been implemented in the educational sector over the past ten years with the aim to enhance the method of teaching and learning. Virtual Reality (VR) is a technology with vast potential and great pedagogical benefits enabling new teaching methods. VR provides an immersive multimedia 3D simulation of real life, supports interactivity with the created environment and enables sensorial experiences. VR has extremely wide applications across various subjects, including physics. Virtual Laboratory technology (VL) is also used in education, in particular for those subjects (e.g. physics, chemistry) that involve running experiments. VL is a highly interactive multimedia environment that brings learners into a virtual world that allows them to create and to conduct simulated experiments, and to visualize in a 3D environment the effects of the experiment. This technology helps learners to enhance their problem solving, computer literacy and practical skills, which are considered important skills for lifelong learning, in an enjoyable way. Benefits of using VL technology in teaching Science are: the experimental activities are completed quicker than in a real word experiment, the same experiment can be run multiple times at no extra cost for materials; it allows for easy observation of the experiment at a time suitable to the learner; and encourages collaboration and communication between teachers and students.

The research work presented in this paper is part of the EU Horizon 2020 NEWTON project that focuses on design, development and deployment of TEL innovative educational solutions for all levels of education, starting from primary to third degree institutions hosted on its learning management system, NEWTON TEL Platform (NEWTELP). NEWTON Project's innovative technologies include Augmented Reality and Virtual Reality (AR/VR) (Bogusevschi, et al., 2018), (Bogusevschi, Bratu, Ghergulescu, Muntean, & Muntean, April 2018), Virtual Teaching and Learning Laboratory (Lynch & Ghergulescu, July 2017a), (Ghergulescu, et al., 2018), Fabrication Labs (Fab Labs) (Togou,

Lorenzo, Lorenzo, Cornetta, & Muntean, July 2018), adaptive and personalised multimedia and multiple sensorial media (multimedia) (Zou, Trestian, & Muntean, 2018), (Bi, et al., 2018), (Moldovan & Muntean, June 2017), personalisation and gamification (El Mawas, Ghergulescu, Moldovan, & Muntean, 2018), (Playfoot, De Nicola, & Di Salvatore, March 2017), (Lynch & Ghergulescu, July 2017b), interactive educational computer-based video games, (El Mawas, et al., 2018). Different innovative pedagogical approaches are also deployed as part of the teaching and learning process such as flipped classroom, game-based and problem-based learning (Muntean, Andrews, & Muntean, July 2017), (Zhao, Chis, Muntean, & Muntean, 2018), (Muntean, El Mawas, Bradford, & Pathak, 2018), (El Mawas, Bradford, Andrews, Pathak, & Hava Muntean, 2018), (Chis, Moldovan, Murphy, Pathak, & Muntean, 2018).

NEWTON Project's TEL learning management platform, NEWTELP, is supporting both teachers and learners with the goal to increase learner quality of experience, where teachers can easily add various interactive content to their lessons and assess its benefits in both learner experience and knowledge gain. A multitude of Small and Large-Scale educational TEL pilots have and are currently being carried out in different European schools and universities, assessing knowledge acquisition benefits, learner experience, learners interest in STEM subjects, platform usability and teachers feedback following the use NEWTON's innovative solutions.

This paper expands on the use of the NEWTON Project 3D immersive *Water Cycle in Nature* application as part of a cases study from the learner experience point of view in addition to previously presented knowledge gain (Bogusevski, et al., 2018). The computer-based VR and VL application focuses on physics terminology which is part of the natural water cycle and precipitation formation, including vaporisation, evaporation, boiling and condensation. The presented case study was employed in Belvedere College, Dublin, Ireland, where one class was appointed as the experimental group interacting with the NEWTON application. Learner experience and application usability when interacting with the *Water Cycle in Nature* application was assessed.

This paper is organised as follows. Next section introduces the theoretical background of the study and describes research work on innovative technologies such as AR, VR, VL, Smart Glasses and Kinect applied in secondary school STEM education, with a focus on Physics topics. This is followed by the *Water Cycle in Nature* application description, including the overview of the case study and its results analysis. The observed conclusions and future plans are summarised in the last section of this paper.

Related Work

Various innovative TEL methods are currently employed in secondary level institution in order to increase students' engagement and interest in STEM subjects. VR is a very popular technology allowing visualisation of various phenomena and concepts enabling students to better grasp complex terminology definitions. For example, its benefits on learners' attitudes toward mathematics and design activities are investigated in (Simsek, 2016) on 28 secondary school third class students, showing increased positive attitudes and interest in mathematics for the experimental group. Another positive example of VR use, specifically in geometry secondary school teaching, is presented in (Guerrero, Ayala, Mateu, Casades, & Alamán, 2016), where mixed reality technology created by combining tangible interfaces and virtual worlds (Mateu, Lasala, & Alaman, 2014) allowed a more meaningful learning ensuring a higher grade of knowledge retention. VR can also play an important role in VLS (Heradio, et al., 2016), which allow visualising various experiments in subjects such as Physics or Chemistry when certain facilities are not available. It needs to be noted that the use of VL has been shown to provide a similar or increased level on knowledge compared to traditional labs (Brinson, 2015).

Another prominent innovative technology employed in STEM secondary school subjects is AR. It is another tool that allows students to better understand difficult topics (Yoon, Anderson, Lin, & Elinich, 2017). In (Wojciechowski & Cellary, 2013) an AR e-learning system for teachers to create AR learning scenes is evaluated on second grade students of a secondary school, exhibiting benefits in terms of enjoyment students displayed during the experimental lessons specialising in chemistry. The benefits of AR were also investigated on 65 12th grade secondary school students when teaching physics, specifically electromagnetism (Ibáñez, Di Serio, Villarán, & Delgado Kloos, 2014), showing a higher level of concentration for the experimental group students with a higher knowledge improvement compared to the control group. The use of AR in Physics lessons was also presented in (Cai, Chiang, Sun, Lin, & Lee, 2017), focusing on magnetic field teaching, showing higher knowledge gain scores and improved attitude in the experimental class students. The beneficial effect of AR technology in chemistry teaching was noted in (Cai, Wang, & Chiang, A case study of Augmented Reality simulation system application in a chemistry course, 2014), especially on low achieving students.

The latest research looked at the use of smartphones, Tablets and Smart Glasses in secondary STEM education. Hochberg et al. (Hochberg, Kuhn, & Müller, 2018), focused on mechanics, and results have shown that

experimental group expressed an improved level of interest and curiosity in the subject when using a smartphone. However, no difference in knowledge acquisition was observed between the classic approach and the experimental one. A Physics app focused on principles behind a pendulum was employed on table PCs and smartphones in (Purba & Hwang, 2017) showing major benefits of visual aids, such as graphs, in scientific learning. Computer simulations were also shown to provide higher knowledge gain in Physics learning compared to traditional methods in (Sarabandoa, Cravinob, & Soares, 2014).

Kuhn investigated the use of Google Smart Glasses when learning Physics concepts (Kuhn, et al., 2016). Results have shown increased curiosity levels when learning physics experiments, but had the same effect on knowledge gain as when using the same platform on tablet PCs.

Kinect technology is another TEL method in STEM education studies. For example, in (Anderson & Wall, 2016) the use of this technology is seen as an important supporting tool in learning kinematics in Physics. A curious example in benefits of innovative technology enhanced experimental Physics learning is investigated in a theme park in (Tho, Chan, & Yeung, 2015).

As Physics involve the study of universal law and the behaviours and relationship among a wide range of physical concepts and phenomena, experiments play a very important role in the teaching and learning process. A common problem faced by many secondary schools is the lack of equipment and materials in their Physics laboratory due to both limited budget available to the school and high maintenance cost of the lab. However, the latest technological advancements such as VR, AR, VL, Smart Glasses, Kinect and smartphone provide now great opportunities for schools to make use of low cost 3D virtual learning environments that support simulations and observations of various experiments. These virtual learning environments allows students to experiment without limitations of space or time and they are available all year, even from home.

Water Cycle in Nature Application Description

The *Water Cycle in Nature* application is an interactive 3D immersive computer-based Physics educational application that combines VL and VR technologies developed by NEWTON Project Consortium Partner, SIVECO from Bucharest, Romania. The educational content is integrated into the VL-VR environment, where the learner is exploring an immersive multimedia 3D simulation of a Nature setting environment and a Laboratory setting environment. The Nature setting provides a description of the natural water cycle definitions, such as vaporisation, evaporation, boiling and condensation and examples of these phenomena occurring in nature, as seen in **Figure 1** (a). The *Water Cycle in Nature* application Laboratory setting aims to provide more detail about the definitions presented in the Nature environment, showing examples of these phenomena in a laboratory or even domestic setting, presented in **Figure 1** (b). To progress through the application, learners need to follow instruction presented in both audio and text formats, as well as sign language for learners with special educational needs, specifically hearing impairment. The definitions presented in the Nature setting are matched with virtual experiments in the Laboratory setting, in order to clarify and ingrain all presented educational content.



a) Nature VR Environment



b) Experimental VL Environment

Figure 1. NEWTON Project *Water Cycle in Nature* Application

The steps followed during the design and development of the *Water Cycle in Nature* were similar to (Paquette, Léonard, Lundgren-Cayrol, Mihaila, & Gareau, 2006) and (Marfisi, George, & Tarpin-Bernard, 2010) and include: Pedagogical Objectives' Specification, Application model, Overall sketch of scenario, virtual laboratory and nature environments, Software components, Detailed description of scenario, virtual laboratory and nature environments, Development of educational content (text and audio-track), Development of Learner Satisfaction assessment, Pedagogical quality control and Application dissemination. Details regarding the application design methodology were provided in (Bogusevschi, et al., 2018).

The application was developed with advice and input on educational content from teachers, and it follows the curriculum and meets the expected learning outcomes.

Case Study Description

Evaluation Methodology

The *Water Cycle in Nature* application was employed and evaluated as part of a case study carried out in a secondary school in Dublin, Ireland. Prior to carrying out the study, ethics approval was obtained from the Dublin City University Ethics Committee and this study meets all ethics requirements. All forms provided to teachers, learners and parents during the case study are listed in Table 1.

Document/From	Experimental Group
Ethics Approval	✓
Consent Form (signed by parents)	✓
Assent Form (signed by students)	✓
Data Management Plan	✓
Plain language statement	✓

Table 1. NEWTON Project *Water Cycle in Nature* application documentation

The case study presented in this paper involves the experimental group of learners and contains several steps, as described in **Table 2**. The experimental class interacted with the *Water Cycle in Nature* application and the purpose of this paper is to describe the Learner Satisfaction Questionnaire experimental group results, as it has been previously shown that the application succeeded to provide a statistically significant higher knowledge gain for the experimental group compared to the control group (Bogusevschi, et al., 2018).

Activity	Experimental Group
Activity 1: Knowledge Pre-test	✓
Activity 2: NEWTON project Approach (<i>Water Cycle in Nature</i> application)	✓
Activity 3: Learner Satisfaction Questionnaire	✓
Activity 4: Knowledge Post-test	✓

Table 2. NEWTON project *Water Cycle in Nature* application case study activities

Participants

The case study presented in this paper was carried out in the Belvedere College Secondary School from Dublin, Ireland, where students of one first year class participated as the experimental group (N = 27), with ages between 12 and 13 years.

Data Collection

During the experimental group lesson, the *Water Cycle in Nature* application was visualised by students on the computer lab PCs, where each participating student had access to a PC. The experimental group teacher supervised the lesson and assisted students in providing directions of use.

The Learner Satisfaction Questionnaire (LSQ) was provided to the experimental class and contained the following questions:

1. The video game and the experiments that I did in the lab from the video (this is called a virtual lab!) helped me to better understand vaporisation and condensation processes.
2. The video game and the experiments that I did in the virtual lab helped me to learn easier about the vaporisation and condensation processes.
3. I enjoyed this lesson that included the video game and the experiments in the virtual lab.
4. The experiments that I did in the virtual lab made the lesson more practical.
5. The video game distracted me from learning.
6. I would like to have more lessons that include video games and doing experiments in virtual labs.
7. Comments/Suggestions.

The LSQ answers for Question 1 to Question 6 were on a 5-level Likert scale, ranging from strongly agree to strongly disagree and standard emojis were used.

Results

User Experience

When evaluating user experience, questions 1 to 6 (Q1 to Q6) described in the Data Collection Section were investigated. Table 3 presents the obtained answers for the 5-level Likert scale - Strongly Agree (SA), Agree (A), Neutral (N), Disagree (D) and Strongly Disagree (SD), showing a good user experience. It was noticed that over 74% of students found the *Water Cycle in Nature* application helpful in better understanding vaporisation and condensation (Q1). Approximately 67% of students believed the application helped them to learn easier about the topics at hand (Q2) and over 74% of students enjoyed the NEWTON project approach. Over half of experimental group students thought the application made the lesson more practical (Q4) and over 70% of students would like to have more lessons using the NEWTON project approach (Q6). Less than 15% of students believed the *Water Cycle in Nature* application distracted them from learning (Q5).

	SA		A		N		D		SD	
	No. of Students	%	No. of Students	%	No. of Students	%	No. of Students	%	No. of Students	%
Q1	3	11.11	17	62.96	7	25.93	0	0.00	0	0.00
Q2	2	7.41	16	59.26	7	25.93	2	7.41	0	0.00
Q3	10	37.04	10	37.04	5	18.52	2	7.41	0	0.00
Q4	4	14.81	11	40.74	9	33.33	3	11.11	0	0.00
Q5	0	0.00	4	14.81	10	37.04	10	37.04	3	11.11
Q6	11	40.74	8	29.63	7	25.93	0	0.00	1	3.70

Table 3. Experimental group Learner Satisfaction Questionnaire, Questions 1 to 6

Usability

The usability of the application was assessed based on learner satisfaction questionnaire answers to Question 7 (Comments/Suggestions). As this question was optional, 14 experimental group students chose to provide no feedback. The remaining 13 students (48%) provided mostly positive feedback regarding the overall applications, with comments including: "I would like to have more classes like this" and "Enjoyable". Three students provided negative feedback regarding the audio-track, commenting that a "more enthusiastic voice-over" would be welcome. This was taken on-board and the application was modified addressing the obtained comments for all future use.

Conclusions

The research work presented in this paper, part of the Horizon 2020 NEWTON Project describes the *Water Cycle in Nature* computer-based VR-VL application for teaching Physics concepts. A description of the application and its educational content focusing on natural phenomena participating in precipitation formation are provided. A case study run in a secondary school investigated the usability of the VR - VL simulation application as a learning environment and its effects on user experience. Feedback on the application and technologies used were collected through a Learner Satisfaction Questionnaire. Together with the previously presented statistically significant knowledge gain obtained by the experimental group when using the application, compared to the control group (Bogusevski, et al., 2018), it was also shown to provide students a good learning experience, as over 74% of students enjoyed learning using the *Water Cycle in Nature* application. Following the participating students' feedback, the application was improved for future small and large-scale pilots. The *Water Cycle in Nature* application is part of a large-scale pilot in various European countries (Ireland, Slovakia and Romania) as part of the Earth Course that is provided to students using multiple NEWTON project technologies (Bogusevski, Muntean, Gorji, & Muntean, 2018) hosted on the NEWTON Project platform - NEWTELP.

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