Primary School STEM Education: Using 3D Computer-based Virtual Reality and Experimental Laboratory Simulation in a Physics Case Study

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Abstract

An educational application, Water Cycle in Nature, that focuses on physics phenomena such as vaporisation and condensation, was employed in a small-scale pilot carried out in a primary school in Ireland, as part of the European Horizon 2020 NEWTON project. 3D immersive computer-based virtual reality and experimental laboratory simulation are part of this application. 58 primary school children took part in this pilot. The goal of the study presented in this paper was to assess the learner experience and usability of the Water Cycle in Nature application. The results analysis shows that most children found the application useful and enjoyable in learning the presented topics.

1. Introduction

It is observed in all levels of education a recent lack of interest in Science, Technology, Engineering, and Mathematics (STEM) subjects, which is mostly due to the perception that these are difficult and demanding subjects. In order to overcome this disengagement from STEM topics, a more interactive and technology-based approach might be the solution, which is also welcomed from a pedagogical point of view. Innovative technology based pedagogies such as gamification and personalised learning path through educational content [1], flipped classroom [2], virtual labs [3], enhanced learning experiences through augmented and virtual reality [4], [5], [6], multiple sensorial media content [7] and interactive educational games [8] , have been employed in class or at home as extra-curricular activities. Virtual Reality (VR) and Virtual Labs (VL), provide an immersive experience through graphical simulation while additional features, such as animation, videos and personalization ensure learners' understanding of complicated theories.

VR and VL also offer an effective way to simplify the understanding and applying STEM complex theory. Various educational studies have been carried out in order to evaluate their benefit on students of various ages in a classroom and informal settings [9].

VR has extremely wide applications across a whole range of disciplines, and the technology has reached a sufficient level of maturity to be applied in education, making VR as an important teaching aid in a wide area of topics, such as medicine in [10], [11] and [12], mathematics and geometry in [13] and [14], and engineering in [15] and [16].

VL, a separate strand of VR, was defined in [17] as a highly interactive multimedia environment that involves users into a computer-generated world. Some of the projects focused on developing online interactive learning environments centred on a functional laboratory that supports collaborative problem solving and enhances students' practical skills are VESLL (Virtual Engineering Sciences Learning Lab http://myweb.lmu.edu/saugust/VESLL/index.htm), which creates a virtual version of a science museum; Virtlab (http://www.virtlab.com/), which is a platform that provides a series of hands-on experiments to be performed in a virtual chemistry laboratory; DoCircuits (www.docircuits.com), which is an online virtual lab for working with circuits online. Employment of a VL in an educational setting is also presented in [18], paper that demonstrating how VL use significantly enhances the teaching experience. Another use of a VL was also investigated in [19] for analysing "real-world" anomalous data, showing that it assisted students in developing new knowledge and preparing them to real-world investigations.

This paper presents *Water Cycle in Nature* application that contains a 3D immersive computer-based VR and experimental laboratory simulations in a VL. By making use of the application, physics phenomena that are part of the nature water cycle and precipitation formation, specifically vaporisation, evaporation, boiling and condensation are studied. This application was developed as part of the Horizon 2020 NEWTON project. A research case study involving children from two Irish primary school classes (one control and one experimental) was carried out. The goal of the research study was to run a small-scale pilot in a primary school in order to evaluate the benefits in learner experience when interacting with the *Water Cycle in Nature* application, compared with the teacher-based classic approach. Both classes had access to the *Water Cycle in Nature*) application, whereby the control group has also been exposed to the classic teaching approach and they had the opportunity to make a comparison between the classic approach and the technology enhanced learning (TEL) approach lessons. A very high percentage of students in both classes showed high level of enjoyment in using the application, voicing hopes that such lessons will be provided in the future and hoping to take part in such novel-approach lessons more often.

The paper is organized as follows. Section 2 provides a brief description of the NEWTON project and an overview of the *Water Cycle in Nature* application. Section 3 presents the case study and its evaluation methodology. The usability and learner experience results are discussed in Section 4. Section 5 summarises the paper, and the conclusions of this research study and presents future plans for both the *Water Cycle in Nature* application and the NEWTON project overall.

2. Water Cycle in Nature Application

The *Water Cycle in Nature* application and the small-scale primary school pilot described in this paper are part of the NEWTON project funded by the EU Horizon 2020 scheme. The project aims to design, develop and deploy innovative solutions for TEL.

Water Cycle in Nature is only one of a wide variety of applications developed as part of this European project which are planned to be employed internationally in small and large-scale pilots. The applications are available via the NEWTON technology enhance learning platform (NEWTELP). The platform integrates and deploys a multitude of novel and emerging mechanisms and TEL methodologies including: interconnected fab labs and virtual labs, multi-modal and multi-sensorial media distribution, augmented reality, gamification, game-based learning, and self-directed learning pedagogies (e.g., flipped classroom, online problem-based learning, and e-practice testing).

The scope of the *Water Cycle in Nature* application is to educate children on precipitation formation and the roles that vaporisation and condensation phenomena play in it, as described in [20]. The two phenomena are described in both a nature environment and a VL environment, allowing children to understand better these concepts. The application was developed with advice and input from teachers.

The *Water Cycle in Nature* application is suitable for both primary and secondary schools, and it has the benefit of being employable in lessons with children with special educational needs, specifically hearing impairments. The children explore the two environments, nature and VL, and they need to follow instruction provided both as a text and as audio track in order to progress through the application. For children with hearing impairments, sign language is used. The audio track, text and, when necessary, sign language provided the educational content as well.

The *Water Cycle in Nature* application design methodology and its steps, including Specification of the pedagogical objectives, Choice of application model, General description of scenario and virtual laboratory, Choice of software components, Detailed description of scenario and virtual laboratory, Development of educational content description (text and audio-track), Knowledge assessment and Learner Satisfaction evaluation development, Pedagogical quality control and Application dissemination are described in more detail in [20].

3. Case Study Description and Evaluation Methodology

The research case study that involved the *Water Cycle in Nature* application was carried out in St. Patrick's Boys National School in Dublin, Ireland, on two classes of 5th class children. Each class had 29 children, and the class was randomly assigned to be either the control or experimental group. The ages of participants ranged from 10 to 11 years old.

Table 1 Water Cycle in Nature: Evaluation Methodology

Activity	***Control Group***	***Experimental Group***
Knowledge Pre-test	✓	✓
Classic Approach (power point presentation)	✓	-
NEWTON project Approach (*Water Cycle in Nature* application)	-	✓
Learner Satisfaction Questionnaire	-	✓
Knowledge Post-test	✓	✓
NEWTON project Approach (*Water Cycle in Nature* application)	✓	-
Learner Satisfaction questionnaire	✓	-

The teachers from the two classes have provided input in the evaluation methodology. The children wishing to take part in this pilot signed Assent Forms, whereas their parents provided signatures on the Consent Form. **Table 1** presents the activities defined in the evaluation methodology for both control and experimental classes in order of their occurrence.

Two separate strands of assessments were defined in the evaluation methodology. One focused on knowledge gain evaluation and the second one on application usability and learner experience.

Pre and post tests were provided to both classes before and after the lesson in order to assess the knowledge gained. The experimental class interacted with the *Water Cycle in Nature* application in order to learn about the water cycle in nature, specifically vaporisation and condensation. The control group was presented the same educational content in a classic approach using a power point presentation presented by their teacher. The post-test questions have evaluated the same topics as the pre-test, using questions that were slightly modified and rephrased versions of the pre-test questions. This assessment did present knowledge improvement following each class.

Table 2 Learner Satisfaction Questionnaire

No.	Question
Q1	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.
Q2	The video game and the experiments that I did in the virtual lab helped me to learn easier about the vaporisation and condensation processes.
Q3	I enjoyed this lesson that included the video game and the experiments in the virtual lab.
Q4	The experiments that I did in the virtual lab made the lesson more practical.
Q5	The video game distracted me from learning.
Q6	I would like to have more lessons that include video games and doing experiments in virtual labs.
Q7	Comments/Suggestions

The second part of the case study, and the focus of this paper, was on application usability and learner experience, and were assessed using a Learner Satisfaction Questionnaire (**Table *2***). A 5-level Likert scale was used, comprising the following options: Strongly Disagree (SD), Disagree (D), Neutral (N), Agree (A) and Strongly Agree (SA). The questionnaire was provided to the experimental group prior the knowledge post-test. The control class, following their classic teaching approach knowledge assessment, has also interacted with the *Water Cycle in Nature* application, and after that they have completed the Learner Satisfaction Questionnaire as well.

4. Results

4.1 Learner Experience

The children experience with the *Water Cycle in Nature* application was assessed for both groups through questions Q1 to Q6 from the Learner Satisfaction Questionnaire. One child from the control class did not provide answers to questions Q4, Q5 and Q6, the remaining students answered all 6 questions. The obtained results for both classes are presented in **Table 3.**

Table 3 Learner experience results

	SA (%)	A (%)	N (%)	D (%)	SD (%)
Q1	31.03	36.21	24.56	6.90	1.72
Q2	37.93	39.66	19.30	3.45	0.00
Q3	62.07	27.59	8.77	0.00	1.82
Q4	29.31	46.55	15.79	6.90	0.00
Q5	15.52	8.62	24.56	20.69	33.33
Q6	70.69	24.14	3.51	0.00	0.00

It is observed that over 67% of children thought that the application helped them better understand the presented topics of vaporisation and condensation. 77% of children thought the *Water Cycle in Nature* application made it easier to learn about the two main topics of the lesson. Almost 90% of children enjoyed the digitised lesson and the presented VL. Over 75 % of children did think that the VL made the lesson more practical, showing that when lab facilities are not available, VLs can be used to present similar experiments. A very high percentage of children (94.83%) said that they would like to have more lessons similar to the *Water Cycle in Nature* application, including the VL. In Q5, a small percentage of children (24%) expressed the opinion that the application distracted them from learning. However, it was observed that some children provided a SA answer to Q5 because of the emoji used, rather than the text of the answer, where the smiley face for the SA option might have confused the participating children, especially when considering the answers provided to the rest of the Learner Satisfaction Questionnaire.

5.2 Application Usability

The Application Usability was assessed based on Comments and Suggestions provided to Q7. 37.9 % of children decided to not provide any comments. A few times it was stated that the audio track needed improvement, which was updated for all future use of the application. Otherwise, most of the comments provided by the remaining 62% of children were positive, including statements such as *"Good lesson", "I enjoyed it and I would do it again", "I would really like them to do it again"* and *"I think [it] was so cool. Thank you so much".*

6. Discussion and Conclusion

The small-scale educational research study presented in this paper was carried out in a primary school in Ireland, as part of the European Horizon 2020 NEWTON project. The research study investigated the learner experience benefits of a TEL approach to learning about precipitation formation by employing a digitised application containing VR and VL environments. 58 5th class students from St. Patrick's Boys National School participated in this study, learning about physics phenomena that are part of the natural water cycle, such as vaporisation, condensation and evaporation. The two classes were randomly assigned as control group and experimental group. The experimental group interacted with the *Water Cycle in Nature* application and the control group was exposed to classic teaching approach, provided by their usual teacher, and the TEL approach via the application, being able to compare between the two.

A Learner Satisfaction Questionnaire was designed to assess learner experience and application usability. Both classes completed this questionnaire, showing excellent overall learner experience, where over 90% of children would like to take part in more such TEL lessons. More than two thirds of participating children from both classes thought the application eased the understanding of the described concepts. Highly positive comments and feedback was obtained from most children.

The *Water Cycle in Nature* application will be actualised, according to some of the children' suggestions and will be part of future international small and large-scale pilots in both primary and secondary schools and in schools for children with hearing impairments. Its effects will also be analysed from a knowledge gain point of view, investigating its benefits on learning improvement and retention.

7. Acknowledgements

This research is supported by the NEWTON project (http://www.newtonproject.eu/) funded under the European Union's Horizon 2020 Research and Innovation programme, Grant Agreement no. 688503.

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