Water Cycle in Nature: Small-Scale STEM Education Pilot

Diana Bogusevschi[1], Irina Tal[2], Marilena Bratu[3], Bogdan Gornea[4], Dorothea Caraman[4], Ioana Ghergulescu[5], Cristina Hava Muntean[2] and Gabriel-Miro Muntean[1]
[1]Dublin City University, Ireland
diana.bogusevschi@dcu.ie, gabriel.muntean@dcu.ie

[2]National College of Ireland, Ireland
irina.tal@ncirl.ie, cristina.muntean@ncirl.ie

[3]University of Bucharest, Romania
marilena.bratu@fpse.unibuc.ro

[4]Siveco, Romania
dorothea.caraman@siveco.ro, bogdan.gornea@siveco.ro

[5]Adaptemy, Ireland
ioana.ghergulescu@adaptemy.com

Abstract: A digitised educational application focused on the water cycle in nature was employed in a small-scale pilot carried out in a secondary school in Ireland, as part of the European Horizon 2020 NEWTON project. The application involved 3D immersive computer-based virtual reality and experimental laboratory simulation. 52 secondary school students (27 in the experimental group and 25 in the control group) took part in the pilot. The goal of the pilot was to assess the effectiveness of the water cycle NEWTON project application in knowledge gain. Pre and post knowledge tests were employed before and after participating students interacted with the application in the experimental group or were provided the classic teacher-based approach in the control group. The results presented show a statistically significant knowledge improvement in the experimental group compared to the control group.

Introduction

Teachers are facing many difficulties when trying to improve the motivation, engagement, and learning outcomes of learners in Science, Technology, Engineering, and Mathematics (STEM) subjects. The disengagement is mainly due to the perception that scientific subjects are difficult. Both teachers and researchers believe that learners' disengagement from STEM area can be overcome by using interactive, engaging, technology-based educational materials in order to support knowledge acquisition through direct experience. Thus, technology-based teaching learning is the future of the education and has already started to be applied at all levels, from primary school to the third level education. Teachers are using computers, pods, and tablets in the class, to help students learn and better understand the concepts.

There has also been a strong pedagogical focus to encourage more students to adopt technology-focused subjects over the past few years. Various innovative approaches to learning and learning environments in STEM education that make use of technology have been researched and deployed in schools. Innovative technology based pedagogies such as 3D interactive educational games (El Mawas, et al., 2018), (Muntean, 2017), flipped classroom (Bradford, Muntean, & Pathak, 2014), virtual labs (August, et al., 2016), fabrication labs (Togou, Lorenzo, Lorenzo, Cornetta, & Muntean, 2018), enhanced learning experiences through augmented and virtual reality (Cai, Chiang, Sun, Lin, & Lee, 2016), (Matcha & Rambli, 2013), enhanced learning using adaptive multimedia (Muntean & Mc Manis, The Value of QoE-Based Adaptation Approach in Educational Hypermedia: Empirical Evaluation, 2006) and mulsemedia content (Zou, et al., 2017) (Bi, Pichon, Zou, Ghinea, & Muntean, 2018) gamification, and personalised learning through educational content (Moldovan & Muntean, 2011), have been proposed to be used during the class sessions or at home as extra activities. Augmented reality and virtual reality, provides an immersive, first-hand experience through graphical simulation while animation, videos and personalization ensures that learners understand complicated theories more easily. These technology-based learning approaches boost learners' engagement, confidence in STEM-related subjects, increase their interest in complex topics and help teachers to deal with disengagement of young people from STEM.

This paper presents the recent development of the *Water Cycle in Nature* application, a 3D immersive computer-based virtual reality (VR) and experimental laboratory simulation which permits students to learn physics concepts such as vaporisation, evaporation, boiling and condensation, related to the natural event of precipitation formation. A research study on two secondary school classes (one control and the other one experimental) was carried out, evaluating the benefits in knowledge acquisition when interacting with the *Water Cycle in Nature* application, compared with teacher-based classic approach. Among the most important findings include the fact that the experimental group students showed a statistically significant knowledge improvement in the post-test scores compared to the pre-test scores, which was not observed in the control group, where the classic teacher-based approach was employed.

The paper is organized as follows. Next section introduces the theoretical background of the study and describes research work on innovative technologies applied in education such as Augmented Reality (AR), VR and Virtual Labs (VL). The following section details our scientific positioning, gives an overview of the *Water Cycle in Nature* application, its design methodology, followed by a description of the research methodology of the case study and its results. Last section summarizes the paper, draws conclusions regarding the research study performed and presents future perspectives.

Related Work

Interpreting new information in the context of where and when it occurs, and relating it to what we already know, develop a better understanding of its relevance and meaning. Therefore, the potential of various innovative technologies applied in education such as AR, VR and VL has been explored in recent years. Educational studies have been performed in order to assess their effectiveness and usefulness in helping students of various ages to better understand a multitude of topics and concepts both in a classroom and informal settings (Lynch & Ghergulescu, 2017).

AR has the capability to add information or meaning to a real object by integrating contextual data to enhance the learning process, providing 3D real models with additional explanations in order to help students broaden their knowledge. The major benefits of applying mixed realities to educational environments consist in providing young users with a better understanding of concepts, and the possibility of resizing and manipulating their augmented representations. AR technology was employed in educational studies covering various topics, including physics in (Enyedy, Danish, Delacruz, & Kumar, 2012), where primary school children were introduced to the concepts of force. The results of this study showed that the use of AR technology, together with an informal play setting, led to a significant improvement in understanding the covered topics for most students. However, the lack of a control group impeded the conclusion that this progress was due to AR or the play setting. The physics subjects was also the part of the study investigating the efficiency of AR described in (Cai, Chiang, Sun, Lin, & Lee, 2016), focused on the topic of magnetic field, which employed both experimental and control groups, where AR was not shown to have a statistically significant improvement in knowledge gain for the experimental group compared to the control group, but it provided a higher learning motivation and interest. Electromagnetism was also part of the study presented in (Ibáñez, Serio, Villarán, & Kloos, 2014). The experimental group displayed a higher level of concentration and a higher improvement in theoretical and visualization questions scores. AR was also shown to be more effective in promoting students' understanding of Electromagnetics.

The importance of AR associated with group interaction was also described in (Matcha & Rambli, 2013) where AR was combined with computer-supported collaborative learning to investigate its benefit on learning science, specifically electricity. It did show benefits of employing AR, however no control group was used in assessing the study results. Another study where AR was used in an informal setting was presented in (Chiang, Yang, & Hwang, 2014), where elementary school children undergoing a natural science course used a location-based AR environment, where students were investigating a nearby pond during a school field trip. The AR technology was shown to immerse students in the learning process more compared to the conventional learning activity. AR was also shown to provide major benefits in an informal setting focused on visitors to a mathematics exhibition in (Sommerauer & Muler, 2014), where certain exhibits were augmented. In a similar setting, specifically a science museum in (Yoon, Anderson, Lin, & Elinich, 2017) focusing on the Bernoulli's principle, the same effect was noted. A much higher knowledge acquisition and understanding of the presented topic was observed in the experimental group in both scenarios. The benefits of AR in assisting junior high-school students in learning solid geometry were shown in (Lin, Chen, & Chang, 2015), especially when low academic students were involved. The same greater knowledge improvement effect on low-achieving students was observed in (Cai, Wang, & Chiang, 2014) in an AR educational study focused on Chemistry. Geometry was also one of the topics in the study presented in (Laine, Nygren, Dirin, & Suk, 2016), where AR was combined with storytelling and gaming in order to assist learners on understanding scientific concepts such as geometry and kinetics. AR technology was also employed in a study on medical students, focusing on forensic medicine in (Albrecht, Folta-Schoofs, Behrends, & Jan, 2013) where was shown that the AR methodology displayed a greater knowledge gain and efficiency.

VR can be thought of as an immersive multimedia 3D simulation of real life by interacting with the created environment and enabling sensorial experiences including virtual tastes, sights, smells, sounds and touches. Carrying out laboratory experiments is an effective way to simplify and clarify the comprehension of STEM complex theory, to understand, conceptualize and apply it. One example of a VR learning experience is zSpace[1] for education, which is designed for student-cantered learning with teachers in as facilitators. zSpace STEM lab consists of zSpace applications that are designed in accordance with standard activities and support materials for STEM education. Some examples of activities include mathematics activities (e.g. area of 3D figures, surface area and volume of 3D solids), physical science, social science, life science, earth and space science related activities.

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. Moreover, the recent hardware and software technological developments have reduced dramatically the cost associated with the use of this technology, making VR as an important teaching aid in a wide area of topics, such as medicine in (Izard, Méndez, & Palomera, 2017), (Sabalic & Schoener, 2017) and (Mirghani, et al., 2016), mathematics and geometry in (Moyer-Packenham, et al., 2016) and (Kaufmann, Schmalstieg, & Wagner, 2000) and engineering in (Fernández & Alonso, 2015) and (Amirkhani & Nahvi, 2016), which also employs a VL in mechanical engineering, showing improvement in knowledge gain for the students in the experimental group.

The authors of (Kim, Park, Lee, Yuk, & Heeman, 2001) have defined a VL as a highly interactive multimedia environment that involves users into a computer-generated world. It offers a simulation of the real world that can be visually explored in a three-dimensional environment and includes sound, real-time motion and tactile capabilities to help users gaining practical experience. A myriad of immersive techniques are combined to support a mixer of theory and practical aspects, the simulation of experiments and to help students in achieving practical skills. A VL also requires active user participation and provides objective feedbacks. Numerous projects propose to develop online interactive learning environments centred on a functional laboratory that supports collaborative problem solving and enhances students' practical skills. One of these projects is VESLL (Virtual Engineering Sciences Learning Lab)[2] that creates a virtual version of a science museum such as the Pacific Science Centre in Seattle or the California Science Centre in Los Angeles. VESLL enhances student learning via multimodal pedagogical strategies, including opportunities for visualization, immediate feedback and innovative techniques for learning evaluation. Virtlab[3] is a platform that provides a series of hands-on experiments to be performed in a virtual chemistry laboratory. Students can build their own simulations using electronic spreadsheets. It contains 8 chapters with experiments. Most of exercises are standalone materials and follow a standard curriculum. DoCircuits[4] is an online virtual lab for working with circuits online. DoCircuits delivers various types of circuits by allowing learners to work with real looking components and devices and run, analyse and save circuits following easy steps. DoCircuits also provides a search functionality of adding tag to the circuits. Tags add a structured view to circuits. The lab includes various types of circuits such as: introductory circuits, advanced circuits, analogue circuits, circuit analysis, digital circuits, power electronics, etc.

Water Cycle in Nature Application

NEWTON Project

The *Water Cycle in Nature* application and its initial testing for knowledge gain described in this paper is part of the NEWTON[5] project. It is one of many such applications which have been or are planned to be employed in small or large-scale education pilots. The main purpose of the *Water Cycle in Nature* application is to educate students

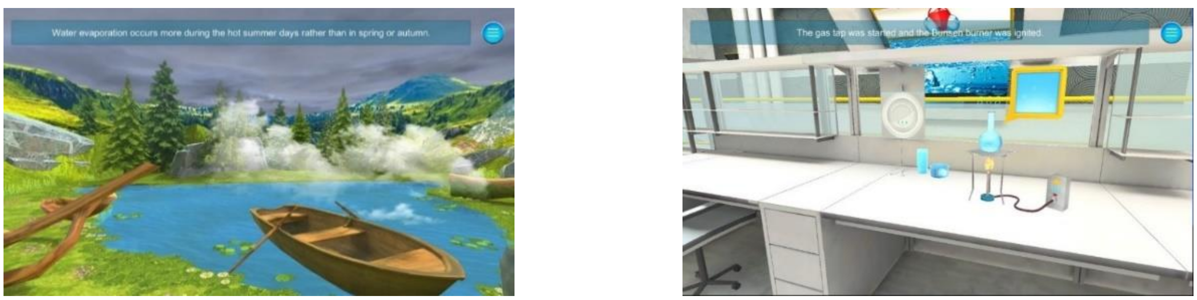
[1] https://zspace.com/
[2] http://myweb.lmu.edu/saugust/VESLL/index.htm
[3] http://www.virtlab.com/
[4] www.docircuits.com
[5] www.newtonproject.eu

on vaporisation and condensation and their roles in the water cycle in nature and precipitation formation. Moreover, this application includes a VL that allows students to perform experiments illustrating condensation and vaporization phenomena.

The European NEWTON project is funded by the EU Horizon 2020 scheme and it designs, develops and deploys innovative solutions for Technology-Enhanced Learning (TEL) involving delivery of state-of-the-art STEM content. The NEWTON project innovative technologies involve adaptive and personalised multimedia and multiple sensorial media (mulsemedia) delivery, Augmented and Virtual Reality (AR/VR)-enhanced learning, Virtual Teaching and Learning Labs (VL), Fabrication Labs (Fab Labs) and Gamification. These technologies are used in conjunction with different pedagogical approaches including self-directed, game-based and problem-based learning methods. NEWTON project also builds an innovative learning management platform allowing cross-European learner and teacher interaction with content and courses and supporting fast dissemination of learning content to a wide audience in a ubiquitous manner. NEWTON project's goal is to make use of TEL in order to increase learner quality of experience, improve learning process and maintain or increase learning outcome.

Application Overview

The *Water Cycle in Nature* application is a VL with interactive content combined with VR technology. Traditional content integrated into the VL is explored by the learner through an immersive multimedia 3D simulation of real life. Students learn about condensation and vaporisation processes via two scenarios: a water cycle in nature VR interactive environment and an experimental activity into 360 degrees' VL.



a) Nature VR Environment b) Experimental VL Environment

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

The application is intended for primary and secondary school students with an additional benefit of being suitable for students with special educational needs, specifically hearing impairments. It is focused on precipitation formation and it provides definitions of various physics terms, such as vaporisation, evaporation, boiling and condensation. The application is divided in two sections. The first part of the application is in a nature environment, depicting a lake and forest, as seen in **Figure 1** (a). The second part is in a virtual laboratory, where physics virtual experiments are visualised in order to explain in more detail the terms defined in the natural environment, as seen in **Figure 1** (b). Students follow instructions provided as text displayed on the screen and audio track (and, when necessary, sign language for students with hearing impairments) in order to progress through each section of the application. To be able to visualise various experiments and natural phenomena, students need to identify targets and locations. The displayed text and audio track also provide educational content.

Both environments, nature VR and experimental VL, have multiple educational steps that need to be visualised by students in order to reach the end of the application. The nature VR environment presents the following phenomena: evaporation, condensation, precipitation and collection. Evaporation and condensation are then presented in the experimental VL environment, where two separate experiments are carried out.

Application Design Methodology

When developing the *Water Cycle in Nature* application the design methodology followed a set of steps, similar to (Paquette, Léonard, Lundgren-Cayrol, Mihaila, & Gareau, 2006) and (Marfisi, George, & Tarpin-Bernard, 2010), which are: 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 development, Pedagogical quality control and Application dissemination.

Specification of the pedagogical objectives: As part of the NEWTON project, applications in a wide range of subjects were planned to be developed, such as physics, chemistry, geography, biology, etc. One of the topics was to describe how some physics concepts observed in laboratories or at home, such as evaporation, vaporisation, condensation, are an important part of the natural phenomena of precipitation formation. The learning objectives for the *Water Cycle in Nature* application are as follows: 1) Effect of incoming solar heat on water 2) Vaporisation description; 3) Difference between vaporisation and evaporation; 4) Effect of temperature and surface on evaporation; 5) Definition of the boiling process; 6) Cloud formation and rain; 7) Simulation of natural phenomena in a virtual laboratory: boiling, evaporation and condensation.

Choice of application model: The application users follow an Investigation model, as they need to follow directions provided by the audio-track and displayed text. Only after finding the application embedded targets and/or arrows participants are allowed to observe various phenomena or virtual laboratory experiments.

General description of scenario and virtual laboratory: Prior developing the application an initial scenario was designed by the project research team in order to achieve all the pedagogical objectives set at the beginning.

Choice of software components: The development of the content was made using a 3D engine. The main reason in selecting the 3D engine is the possibility to port the same content on several platforms. The content developed within the project is available on Windows and Android devices. Another reason for choosing the 3D engine was the support from community. It's a great advantage to have multiple online resources available at your disposal if a problem is encountered.

Detailed description of scenario and virtual laboratory: Individual scenes' illustrations were created in order to comply with all pedagogical objectives of the application. Mainly the learner explores various environments in order to observe natural phenomena in VR or VL experimental settings.

Development of educational content description: The *Water Cycle in Nature* application has embedded an audio-track and text displayed, both providing educational content. The text for both was developed using pedagogical experts in order to meet the learning objectives.

Knowledge assessment development: The NEWTON project research team and its pedagogical experts developed the knowledge pre and post-tests, in order to assess the application's benefit learning impact.

Pedagogical quality control: Extensive interaction with teachers was carried out during multiple stages of application development, including the detailed description of scenario, knowledge assessment and development of educational content text stages, in order to validate and obtain approval. Following teachers' feedback and advice, all these elements were modified and adjusted.

Application dissemination: After completing the application, obtaining approval from teachers and agreeing on a schedule suitable to the participating school, the *Water Cycle in Nature* application was provided to students for the initial case study.

Water Cycle in Nature Application Small-scale Pilot

Evaluation Methodology

The *Water Cycle in Nature* small-scale NEWTON project pilot was composed of various stages. Prior to undertaking this pilot, ethics approval was obtained from the DCU Ethics Committee and this evaluation meets all ethics requirements. The application was developed with advice and input on educational content from teachers, who also chose the class most suitable for the presented educational content. All the educational content presented to the students was reviewed and agreed with the teachers in order to make sure that it subscribes to curriculum and meets the expected learning outcomes. Consent forms were provided to parents and assent forms were signed by students willing to participate in this study. A description of the project and small-scale pilot were provided in a plain language statement and the data management plan was also made available. In terms of knowledge gain evaluation and analysis, two student groups from the same school and of the same age were employed, specifically control and experimental groups. The control group was presented the educational content in a classic manner by their usual teacher. The experimental group used the NEWTON project *Water Cycle in Nature* application to learn about the same topic. In order to ensure the same educational content was presented to both groups, a power point presentation was used by the control group teacher, which matched all definitions and explanations present in the *Water Cycle in Nature* application.

Prior to being exposed to the learning content, a pre-test was provided to both control and experimental groups in order to assess their knowledge of the topic. A post-test assessed students' knowledge gain either after their interaction with the NEWTON project application for the experimental group, or after being exposed to the classic approach for the control group. The tests were devised with the help of participating teachers with slight variations between the pre-test and post-test questions. Noteworthy is the fact that both sets of questions (pre-test and post-test ones) assess the same learning outcomes.

Participants

The NEWTON project small-scale pilot employing the *Water Cycle in Nature* application was carried out in the Belvedere College Secondary School from Dublin, Ireland where students of two first year classes participated. One class was randomly assigned as the experimental group and the parallel class was assigned to participate as the control group. The students were between 12 and 13 year old. The experimental group had 27 students and 25 students participated in the control group. Both classes have 28 students, however one student was absent in the experimental group and two in the control group, and one student did not receive parents' consent in the control group.

Data Collection

The control group was presented the educational content in a classic manner using a power-point presentation developed by the teacher after he reviewed the NEWTON project application. For the experimental group, the *Water Cycle in Nature* application was uploaded on the school server, and 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, which were developed by the NEWTON project researchers. The same NEWTON project researcher was present in both control and experimental group lessons, which ran consecutively, assisting the teacher when necessary, collecting the paper-based knowledge tests and questionnaires. Student IDs were employed for both groups, in order to ensure anonymization.

The knowledge pre-test contained seven questions, where four were open-ended, two were multiple choice (one with one correct answer and one with multiple correct answer) and one True/False question. The knowledge post-test contained eight questions, where four questions were multiple-choice, two of which with one correct answer and two with multiple correct answers; two True/False questions and two open-ended questions.

Results

Learning Impact

Both the experimental and control groups showed a comparable level of knowledge of the topic prior to the NEWTON approach and classic approach lessons. The average pre-test scores for the experimental group was 5.83 points (out of 10), slightly higher than the control group's 5.52 points. The results of a t-test also confirmed no significant difference between the two groups prior the lessons, either the experimental or classic approach, at $\alpha = 0.05$ ($t(50) = 0.65044$, $p = 0.518$).

Firstly, the comparison between the experimental and control class was assessed in terms of the number of students with improved post-test score when compared with the pre-test score. 74% (20 out of 27) of experimental group students showed knowledge improvement after using the NEWTON project application, whereas 48% (12 out of 25) of control group students showed improvement after the classic approach. Secondly, the average post-test scores also showed a bigger improvement for the experimental group, with an average of 6.7 points (out of 10), which is a 14.9% improvement compared to the pre-test average score, compared to 5.65 points for the control group, which is a 2.36% improvement. A t-test showed statistically significant difference between the post-test results compared to the pre-test results for the experimental group, at $\alpha = 0.05$ ($t(26) = 2.865$, $p = 0.008$). The t-test for the control group's post-test results compared to its pre-test results displayed improvement of no statistical significance, at $\alpha = 0.05$ ($t(24) = 0.282$, $p = 0.7805$).

No student from the control group obtained full marks for both pre and post-test, and one student from the experimental group obtained full marks for the post-test, with no one from that group obtaining full marks for the pre-test. Regarding the pre-test results, a higher percentage of students from the experimental group obtained full marks for four out of the seven pre-test questions, which were the two open-end questions and both multiple choice questions, as seen in **Table 1**. An analysis of the post-test results show that the experimental group had a higher percentage of students with full marks for five out of the eight post-test questions, which were all four multiple choice questions and one open-end question, as seen in **Table 2**.

Pre-test Questions	Experimental Group		Control Group	
	No. of Students with full marks	%	No. of Students with full marks	%
Overall Pre-test Grade	0	0.00	0	0.00
Q1 (Open-end Question)	15	55.56	15	60.00
Q2 (Open-end Question)	0	0.00	1	4.00
Q3 (Open-end Question)	14	51.85	11	44.00
Q4 (Open-end Question)	4	14.81	3	12.00
Q5 (Multiple choice question - multiple correct answers)	12	44.44	9	36.00
Q6 (Multiple choice questions - one correct answer)	13	48.15	8	32.00
Q7 (True/False Question)	22	81.48	24	96.00

Table 1. Number and percentage of students with full marks in the Pre-test

Post-Test Questions	Experimental Group		Control Group	
	No. of Students with full marks	%	No. of Students with full marks	%
Overall Post-Test Grade	1	3.70	0	0.00
Q1 (Multiple choice questions - one correct answer)	21	77.78	18	72.00
Q2 (Multiple choice questions - one correct answer)	24	88.89	22	88.00
Q3 (Multiple choice question - multiple correct answers)	7	25.93	2	8.00
Q4 (Multiple choice question - multiple correct answers)	15	55.56	4	16.00
Q5 (Open-end Question)	18	66.67	19	76.00
Q6 (Open-end Question)	12	44.44	10	40.00
Q7 (True/False Question)	21	77.78	20	80.00
Q8 (True/False Question)	24	88.89	25	100

Table 2. Number and percentage of students with full marks in the Post-test questions

Post-test Average points sub-group	Experimental Group		Control Group	
	No. of Students	%	No. of Students	%
7 to 10 points	17	62.96	6	24
5 to 7 points	4	14.81	12	48
0 to 5 points	6	22.22	7	28

Table 3. Number and percentage of experimental and control group students with post-test average grades in three sub-groups: above 7 points, between 5 and 7 points, and below 5 points.

Pre-test Average points sub-group	Experimental Group		Control Group	
	No. of Students	%	No. of Students	%
7 to 10 points	8	29.63	7	28
5 to 7 points	13	48.15	9	36
0 to 5 points	6	22.22	9	36

Table 4. Number and percentage of experimental and control group students with pre-test average grades in three sub-groups: above 7 points, between 5 and 7 points, and below 5 points.

When comparing the average post-test grades between the two groups, it is observed that a much higher percentage of students in the experimental group achieved grades higher than 7 points (out if maximum 10), at approximately 63%, compared to 24% for the control group. 48% of control group students achieved grades between 5 and 7 points and 28% of students from this group had grades below 5 points. Whereas the experimental group had around 22% of students in the lowest points post-test sub-group and approximately 15% of students were in the middle point group, as displayed in **Table 3**. If comparing this to their pre-test results, displayed in **Table 4**, it is observed that the biggest jump is for the experimental group, where over 33% of students moved from the 5 to 7 points sub-group to the 7 to 10 points sub-group, whereas in the control group, the number of students in the highest points sub-group decreased by 4% and the number of students in the middle points sub-group showed the biggest improvement for the control group, of 12%.

Conclusions

The small-scale educational pilot described in this paper investigates the benefit of the NEWTON project *Water Cycle in Nature* computer-based virtual laboratory simulation in knowledge gain. A description of the application and its educational content focusing on natural phenomena regrading precipitation formation, such as vaporisation, evaporation and condensation, are provided. A small-scale pilot was conducted in Belvedere College, a secondary school located in Dublin, Ireland. Two classes of students took part in the case study, one class exposed to the NEWTON project application as the experimental group and the other class as the control group, where the classic teacher-based approach was used. 27 students were part of the experimental group and 25 students were part of the control group. Both participating groups where provided knowledge tests before and after the lessons, teacher-based or computer-based, in order to assess the learning outcomes for each teaching approach. After the post-tests were analysed, it was shown that the use of the computer-based application during the experimental group lesson showed a statistically significant knowledge gain compared to the pre-test evaluation. The control group did achieve learning improvement; however, it was of no statistical significance compared to their pre-lesson knowledge. It was also noticed that in the experimental group the biggest jump of 9 students, or 33.33%, was from the mid-grade pre-test sub-group (5 to 7 points out of 10) to the high-grade post-test sub-group (7 to 10 points out of 10), whereas in the control group the biggest improvement was observed in the mid-grade range, of 3 students, or 12%. The *Water Cycle in Nature* application is scheduled to be part of a large-scale pilot in various European countries (Ireland, Slovakia and Romania) as part of the Earth Science course (Bogusevschi, Muntean, Gorgi, & Muntean, 2018) that will be provided to students using multiple NEWTON project technologies.

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.

References

Aji, C. A., & Khan, M. J. (2015). Virtual to Reality: Teaching Mathematics and Aerospace Concepts to Undergraduates using unmanned aerial systems and flight simulation software. *Journal of College Teaching & Learning, 12*(3), 177-188.

Ak, O., & Kutlu, B. (2017). Comparing 2D and 3D game-based learning environments in terms of learning gains and student perceptions. *British Journal of Educational Technology, 48*(1), 129-144.

Albrecht, U.-V., Folta-Schoofs, K., Behrends, M., & Jan, U. v. (2013). Effects of Mobile Augmented Reality Learning Compared to Textbook Learning on Medical Students: Randomized Controlled Pilot Study. *Journal of Medical Internet Research, 15*(8), 182.

Amirkhani, S., & Nahvi, A. (2016, July). Design and implementation of an interactive virtual control laboratory using haptic interface for undergraduate engineering students. *Computer Applications in Engineering, 24*(4), 508-518.

August, S. E., Hammers, M. L., Murphy, D. B., Neyer, A., Gueye, P., & Thames, R. Q. (2016). Virtual Engineering Sciences Learning Lab: Giving STEM Education a Second Life. *IEEE TRANSACTIONS ON LEARNING TECHNOLOGIES, 9*(1), 18-30.

Bi, T., Pichon, A., Zou, L. C., Ghinea, G., & Muntean, G.-M. (2018). A DASH-based Mulsemedia Adaptive Delivery Solution. *ACM Multimedia Systems Conference (MMSys), International Workshop on Immersive Mixed and Virtual Environment Systems (MMVE).* Amsterdam, The Netherlands.

Bogusevschi, D., Muntean, C.-H., Gorgi, N., & Muntean, G.-M. (2018). EARTH COURSE: PRIMARY SCHOOL LARGE-SCALE PILOT ON STEM EDUCATION. *EDULearn.* Palma de Mallorca,Spain.

Bradford, M., Muntean, C., & Pathak, P. (2014). An Analysis of Flip-classroom Pedagogy in First Year Undergraduate Mathematics for Computing. *Proceedings of the 44th IEEE Frontiers in Education Conference (FIE), Madrid*, (pp. 1-5).

Cai, S., Chiang, F.-K., Sun, Y., Lin, C., & Lee, J. J. (2016). Application of augmented reality-based natural interactive learning in magnetic field instruction. *Interactive Learning Environments*.

Cai, S., Wang, X., & Chiang, F.-K. (2014). A case study of Augmented Reality simulation system application in a chemistry course. *Computers in Human Behaviour, 37*, 31-40.

Carmigniani, J., & Furht, B. (2011). "Augmented Reality: An Overview". In *Handbook of Augmented Reality* (pp. 3-46). New-York: Springer-Verlag.

Cheng, K.-H., & Tsai, C.-C. (2013). Affordances of Augmented Reality in Science Learning: Suggestions for Future Research. *Journal of Science Education & Technology, 22*(4), 449-462.
Chiang, T. H., Yang, S. J., & Hwang, G.-J. (2014). Students' online interactive patterns in augmented reality-based inquiry activities. *Computers & education, 78*, 97-108.
Daineko, Y., Dmitriyev, V., & Ipalakova, M. (2017, January). Using virtual laboratories in teaching natural sciences: An example of physics courses in university. *Computer Applications in Engineering Education, 25*(1), 39-47.
Dunleavy, M. (2014). "Design Principles for Augmented Reality Learning". *TechTrends, 58*(1), 28–34.
El Mawas, N., Tal, I., Moldovan, A. N., Bogusevschi, D., Andrews, J., Muntean, G.-M., & Hava, M. C. (2018). Final Frontier Game: A Case Study on Learner Experience. *Proceedings of the 10th International Conference on Computer Supported Education (CSEDU), Madeira, Portugal.*
Enyedy, N., Danish, J. A., Delacruz, G., & Kumar, M. (2012). "Learning physics through play in an augmented reality environment". *International Journal of Computer-Supported Collaborative Learning, 7*(3), 347-378.
Fernández, R. P., & Alonso, V. (2015, March). Virtual Reality in a shipbuilding environment. *Advances in Engineering Software, 81*, 30-40.
Ibáñez, M. B., Serio, Á. D., Villarán, D., & Kloos, C. D. (2014). Experimenting with electromagnetism using augmented reality: Impact on flow student experience and educational effectiveness. *Computers and Education, 71*, 1-13.
Izard, S. G., Méndez, J. A., & Palomera, P. R. (2017, May). Virtual Reality Educational Tool for Human Anatomy. *Journal of Medical Systems*, 41-76.
Kamarainen, A., Metcalf, S., Grotzer, T., Browne, A., Mazzuca, D., Tutwiler, M. S., & Dede, C. (2013). EcoMOBILE: Integrating augmented reality and probeware with environmental education field trips. *Computers and Education, 68*(10), 545-556.
Kaufmann, H., Schmalstieg, D., & Wagner, M. (2000, December). Construct3D: A Virtual Reality Application for Mathematics and Geometry Education. *Education and Information Technologies, 5*(4), 263-276.
Kim, J.-H., Park, S.-T., Lee, N., Yuk, K.-C., & Heeman, L. (2001). *Virtual Reality Simulations in Physics Education.* Retrieved from Imteractive Multimedia Electronic Journal of Cumputer-enhanced Learning: http://imej.wfu.edu/articles/2001/2/02/index.asp
Laine, T. H., Nygren, E., Dirin, A., & Suk, H.-J. (2016, June). Science Spots AR: a platform for science learning games with augmented reality. *Educational Technology Research and Development, 64*(3), 507–531.
Lim, C., & Park, T. (2011). Exploring the educational use of an augmented reality books. *Annual Convention of the Association for Educational Communications and Technology.* Florida.
Lin, H.-C. K., Chen, M.-C., & Chang, C.-K. (2015). Assessing the effectiveness of learning solid geometry by using an AR-assisted learning system". *Interactive Learning Environments, 23*(6), 799-810.
Lynch, T., & Ghergulescu, I. (2017). Review of Virtual Labs as the Emerging Technologies for Teaching STEM Subjects. *11th International Technology, Education and Development Conference, 6-8 March, 2017, Valencia, Spain.*
Marfisi, I., George, S., & Tarpin-Bernard, F. (2010). Tools and methods for efficiently designing serious games. *Proceedings of the 4th Europeen Conference on Games Based Learning ECGBL*, (pp. 226-234).
Martin-Gonzalez, A., Chi-Poot, A., & Uc-Cetina, V. (2015). Usability evaluation of an augmented reality system for teaching Euclidian vectors. *Innovations in education and teaching International, 53*(6), 627-636.
Matcha, W., & Rambli, D. R. (2013). Exploratory study on collaborative interaction through the use of Augmented Reality in science learning. *Procedia Computer Science.*
McMahon, D. D., Cihak, D. F., R. E., & Bell, S. M. (2016). Augmented Reality for teaching Science Vocabulary to Postsecondary Education Students with Intellectual Disabilities and Autism. *Journal of research on Technology in Education, 48*(1).
Mirghani, I., Mushtaq, F., Allsop, M., Al-Saud, L., Tickhill, N., Potter, C., . . . Manogue, M. (2016). Capturing differences in dental training using a virtual reality simulator. *uropean Journal of Dental Education*.
Moldovan, A.-N., & Muntean, C. H. (2011). Towards Personalised and Adaptive Multimedia in M-learning Systems. *Proceedings of World Conference on E-Learning in Corporate, Government, Healthcare, and Higher Education. Association for the Advancement of Computing in Education (AACE), Chesapeake, VA*, (pp. 782-791).
Moyer-Packenham, P. S., Bullock, E., Shumway, J. F., Tucker, S. I., Watts, C., Westenskow, A., . . . Jordan, K. E. (2016). The role of affordances in children's learning performance and efficiency when using virtual manipulative mathematics touch-screen apps . *Mathematics Education Research Journal, 28*(1), 79-105.
Muntean, C., & Mc Manis, J. (2006). The Value of QoE-Based Adaptation Approach in Educational Hypermedia: Empirical Evaluation. *International Conference on Adaptive Hypermedia and Adaptive Web-Based Systems* (pp. 121-130). Lecture Notes in Computer Science, vol 4018. Springer, Berlin, Heidelberg.
Muntean, C., Andrews, J., & Muntean, G.-M. (2017). Final Frontier: An Educational Game on Solar System Concepts Acquisition for Primary Schools. *IEEE 17th International Conference on Advanced Learning Technologies (ICALT)*, (pp. 335-337). Timisoara.
Paquette, G., Léonard, M., Lundgren-Cayrol, K., Mihaila, S., & Gareau, D. (2006). Learning Design based on Graphical Knowledge-Modelling. *9*(1).
Sabalic, M., & Schoener, J. D. (2017). Virtual Reality-Based Technologies in Dental Medicine: Knowledge, Attitudes and Practice Among Students and Practitioners. *Technology, Knowledge and Learning, 22*(2), 199-207.
Sommerauer, P., & Muler, O. (2014). Augmented Reality in informal learning environments: a field experiment in a mathematics exhibition. *Computers & Education, 79*, 59-68.
Tan, Q., Chang, W., & Kinshuk. (2015). Location-based augmented reality for mobile learning: algorithm, system, and implementation. *The electronic Journal of e-Learning, 13*(2), 138-148.

Togou, M. A., Lorenzo, C., Lorenzo, E., Cornetta, G., & Muntean, G.-M. (2018). Raising Students' Interest in STEM Education Via Remote Digital Fabrication: An Irish Primary School Case Study. *EDULEARN*, . Palma de Mallorca, Spain.
Toth, E. E. (2016, February). Analyzing “real-world” anomalous data after experimentation with a virtual laboratory. *Educational Technology Research and Development*, *64*(1), 157-173.
Wu, H.-K., Lee, S. W.-Y., Chang, H.-Y., & Liang, J.-C. (2013, March). “Current status, opportunities and challenges of augmented reality in education”. *Computers & Education*, *62*(3), 41-49.
Yoon, S., Anderson, E., Lin, J., & Elinich, K. (2017). How Augmented Reality Enables Conceptual Understanding of Challenging Science Content. *Educational Technology & Society*, *20*(1), 156-168.
Zou, L., Tal, I., Covaci, A., Ibarrola, E., Ghinea, G., & Gabriel-Miro, M. (2017). Can Multisensorial Media Improve Learner Experience? *ACM Multimedia Systems Conference (MMSys), Taipei, Taiwan, China.*