Improving STEM Learning Experience in Primary School by Using NEWTON Project Innovative Technologies

Nour El Mawas[1(✉)], Irina Tal[2], Arghir Nicolae Moldovan[2], Diana Bogusevschi[3], Josephine Andrews[2], Gabriel-Miro Muntean[3], and Cristina Hava Muntean[2]

[1] CIREL(EA 4354), University of Lille, Lille, France
nour.el-mawas@univ-lille.fr

[2] School of Computing, National College of Ireland, Dublin, Ireland
{Irina.Tal,ArghirNicolae.Moldovan,Josephine.Andrews, Cristina.Muntean}@ncirl.ie

[3] School of Electronic Engineering, Dublin City University, Dublin, Ireland
{diana.bogusevschi,Gabriel.Muntean}@dcu.ie

Abstract. Nowadays school curriculum is changing and more and more teachers are incorporating STEM content and themes into their classrooms. Students need to be proficient in STEM fields in order to be ready for the new technology driven society. Game-based learning and the latest visual technologies such as Augmented Reality, Virtual Reality and Virtual Labs can motive students to study STEM topics through an immersive and engaging environment. This research introduces NEWTON project that integrates into a learning platform (NEWTELP) different innovative technologies and deploys them in various European learning environments. In particular, Final Frontier, a novel interactive educational video game about solar system designed for primary school children is presented. A research study that involved the use of the game in a primary Irish school from Dublin, has investigated the learner experience. An analysis of the results show that over 90% of students confirmed that the game helped them to learn about the characteristics of the planets from the Solar system and they enjoyed the game and the game features in particular the fun aspect, the exploration tasks, stars and meteorites collection, avatar, use of jetpack, and the interactive puzzles.

Keywords: Technology enhanced learning · STEM · Educational video game · Primary education · Solar system

1 Introduction

STEM stands for science, technology, engineering, and math and it has become more than a popular buzzword. Nowadays school curriculum is changing and more and more teachers are incorporating STEM content and themes into their classrooms. Students need to be proficient in STEM fields in order to be ready for the new technology driven society. The new 21st century STEM oriented teaching and learning paradigm replaces the old approach in which the teacher is the only source of all the knowledge, everyone

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learns the same way, and the class is the only place in which knowledge is transmitted. The 21st century teaching and learning paradigm is dynamic, technology-enabled, student-centric and develops 21st century competencies and skills such as digital literacy, communication, collaboration, critical thinking, problem solving, decision making and creativity.

The latest technological innovations such as virtual reality (VR), augmented reality (AR), educational 3D games integrated into the teaching and learning process increase student motivation and engagement. in STEM subjects, demystify the pre-conceived idea among students that science and technologies subjects are difficult and not at last improve learning outcome and increases student motivation and engagement.

Many VR applications are currently designed for entertainment, but VR's potential for education is huge. VR devices are expected to increase 85% by 2020, with gaming and educational applications driving most of that growth [49]. A few companies (e.g. ZSpace), have already created specialized VR systems for education purpose that help children complete STEM tasks in a hands-on environment.

AR technology integrates digital information with real environments in which people live. AR offers a new form of interactivity between the physical and virtual world and has become one of the key emerging technologies in education. A systematic review on the use of AR technology to support STEM learning found that most augmented reality applications for STEM learning offered exploration or simulation activities However, few studies provided students with assistance in carrying out learning activities [17].

Game-based learning involves the use of gaming technology for educative purposes where students explore concepts in a learning context designed by teachers. Game-based learning helps the students learn in an immersive and engaging environment.

Educational games are now applied at all levels of education, from primary school to the third level education. In 2015, 47% of K-12 teachers reported that they use game-based learning in their classrooms, and almost 66% of K-5 teachers mentioned the use of digital games in their curriculum [8]. Currently increasing number of students are exposed to game-based learning in their formal, non-formal and in-formal education and this trend is expected to continue. For instance, the TechNavio's report published in August 2017 [40] forecasts that K-12 game-based learning market is expected to grow at a compound annual growth rate of nearly 28% during the period 2017–2021.

The growing importance of Science, Technology, Engineering, Mathematics (STEM) education is also driving the growth of game-based learning market. This is due to the fact that educational games encourage students to get involved in live projects or real-time activities so that they can learn by experimenting [34]. The game-based learning pedagogy also boosts students' confidence in STEM-related subjects, increase their interest in complex topics and helps teachers to deal with disengagement of young people from STEM.

The research work reported in this paper focuses on the use of the latest technological innovations to help students learn about STEM. A review on the use of games, Virtual Reality, Augmented Reality, Virtual Labs, Multimedia and mulsemedia in education is presented. In this context, the European Union-funded Horizon 2020 NEWTON project [30] is introduced. NEWTON Project proposes and integrates diverse novel technologies in STEM education including adaptive multimedia and multi-sensorial content delivery mechanisms [1, 25, 48] personalisation and gamification solutions [21, 32], introduces virtual labs and fabrication labs [22, 43] and employs problem-based, game-oriented, and flipped-classroom-based learning [28]. As part of the NEWTON project, a number of small and large scale pilots were run. In particular, the large scale Earth Science pilot includes a set of educational applications for primary school education, that cover a set of topics in the areas of Atmosphere, Geosphere, Biosphere and Astronomy. The Astronomy topic is taught through an immersive educational game called Final Frontier. The paper also presents a research study on learner experience when the game was used in the class.

The paper is organized as follows. Section 2 introduces some research projects that investigated the use of various technologies in the teaching and learning process. Sections 3 and 4 details our scientific positioning, gives an overview of the NEWTON project focusing on the *Final Frontier* game description and game design methodology. Section 5 presents research methodology of the case study and its results. Section 6 summarizes the paper, draws conclusions regarding the research study performed and presents future perspectives.

2 Related Work

2.1 Gamification and Game-Based Learning

Gamification and game-based learning (GBL), have drawn the attention of many researchers and educators over the past years. While there are various definitions and interpretations of gamification, one common definition is that gamification represents the integration of game elements into gameness objects in order to have gameful characteristics [45]. Such game elements or mechanics include: points, badges, levels, progress bars, leader boards, virtual currency, and avatars [7]. Some criticism of gamification is that often the implementations lack thorough theoretical foundation and are too focused on extrinsic motivation by being too reliant on points, badges and leader boards [35]. A number of research studies have showed that gamification can have positive effects on the learning performance as well as on motivational aspects such as engagement, participation and enjoyment [15, 35]. However, the results were not always consistent, with some arguing that the results may be the result of the novelty aspect and not have long-term impact [15].

GBL represents an educational approach that integrates video games with defined learning outcomes. The appeal of using video games in education can be partially explained by the need to reach today's digital learners that have continuous access to entertainment content through the Internet. At the same time, games provide highly engaging activities that are stimulating, generate strong emotions, require complex information processing, provide challenges and can support learning and skill acquisition [3]. The learning experiences and outcomes of educational games can be classified into several classes which include: knowledge acquisition, practising and processing (content understanding), knowledge application (skill acquisition), reflection (behaviour change) and knowledge anticipation (motivation outcomes) [18].

Previous research works have shown that game-based learning can have positive effects on important educational factors such as student motivation and engagement [13], learning effectiveness [10], as well as learning attitude, achievement and self-efficacy [39]. Moreover, game-based learning has the potential to facilitate the acquisition of 21st century skills such as critical thinking, collaboration, creativity and communication [33]. While there is much research evidence of GBL benefits, some studies failed to reproduce them or obtained contradictory findings. Tobias et al., argue that this may be due to lack of design processes that effectively integrate the motivational aspects of games with good instructional design to ensure learners acquire the expected knowledge and skills [42]. The authors also made recommendations for educational game design, such as to provide guidance, use first person in dialogues, use animated agents in the interaction with players, use human rather than synthetic voices, maximise user involvement and motivation, reduce cognitive load, integrate games with instructional objectives and other instruction, use teams to develop instructional games [42].

One common criticism of game-based learning studies is that they lack foundation in established learning theories. A meta-analysis of 658 game-based learning research studies published over 4 decades, showed that the wide majority of studies failed to use a learning theory foundation [44]. Among the studies that had a pedagogical foundation, constructivism appears to be the most commonly used as indicated by multiple review papers [20, 33, 44]. Other learning theories that were also implemented by different research studies include: cognitivism, humanism and behaviourism. Common learning principles employed by game-based learning studies include among others: experiential learning, situated learning, problem-based learning, direct instruction, activity theory, and discovery learning [44].

Few studies have proposed and/or evaluated educational games related to planets or the solar system [28]. *HelloPlanet* is a game where the player can observe and interact with a planet that has a dynamic ecosystem, where the player can simulate organisms, non-organisms, terrains, and more [37]. The game evaluation results from 41 primary and secondary school children, showed a statistically significant learning gain for both girls and boys, and an effect on interest in STEM for girls, but not for boys. The *Space Rift* game enables students to explore the Solar system in a virtual reality environment [31]. However, the game evaluation involved only 5 students and was mostly focused on usability rather than educational aspects. The *Ice Flows* game aims to educate the users about the environmental factors such as temperature and snowfall on the behaviour of the Antarctic ice sheet [19]. However, the game was either not evaluated or the results were not published yet.

A recent systematic review of game-based learning in primary education has indicated that games were used to teach a variety of subjects, among which the most popular being Mathematics, Science, Languages and Social Studies [14]. However, the review authors also concluded that more research studies are needed to evaluate the pedagogical benefits of GBL at primary level.

2.2 Multimedia, Mulsemedia and Virtual Reality in Learning

In the last years, the technological landscape allowed for the usage of multimedia in education to become quite common. There is a lot of research that demonstrated the benefits of multimedia in education, benefits that can be augmented with the adaptation and personalization of the content to the learner context and needs [26, 46]. Learner context can encompass for instance characteristics of the device used during learning (e.g. CPU, screen resolution, battery life, etc.) or network conditions (e.g. throughput, loss, latency, etc.). Finding the right balance between content adaptation and learner quality of experience is difficult, but highly important. However, there is a natural desire to increase learner quality of experience, especially in learning context [27].

Multimedia is popular in education as it was demonstrated that when both text and supporting pictures are used in the learning process, a higher level of understanding and recall is achieved by learners than when text only is used in the learning process [11]. Moreover, neuroscience states that human brain is multisensorial and the more senses are involved in the learning process the deeper the learning is [36]. Mulsemedia represents a step further to the classic multimedia; it is a type of media that involves more than the two senses (i.e. sight and hearing) stimulated by multimedia. There are very recent studies that are focused on analysing the impact of mulsemedia on the learning process and the degree of acceptability of mulsemedia by the students as a technology used in learning [6]. In [47], a study carried out with 42 master students employed a mulsemedia-enhanced teaching approach in order to assess the impact of mulsemedia content on learner experience. The results of the study demonstrated that mulsemedia had a very positive impact on students' experience. All the students that participated in the study stated that they enjoyed the multisensorial experience during the class. Additionally, a vast majority of students agreed that the multi-sensorial effects associated with mulsemedia have not distracted them from learning and that they would like to have more such classes. More recent studies have assessed the influence of mulsemedia content on learning process, showing how it helps increase not only learner satisfaction, but also learning outcome [1, 41].

Virtual Reality is able to provide immersive experiences using a computer-generated environment. In general, it is focused on the two senses that multimedia is focused on, but the trend is to combine multi-sensorial effects (e.g. haptic effects, tactile effects, etc.) for a truly immersive experience, just like mulsemedia. Virtual reality in education provides students with authentic learning experiences and facilitates students in visualizing different complex and difficult models [16]. There are a considerable amount of studies and surveys that are analysing the impact of virtual reality in education [12, 16, 24]. The general conclusion is that virtual reality has a very positive impact on learning, it increases learner engagement, allows for constructivist learning and stimulates learner creativity.

It is envisioned that mulsemedia and virtual reality will become very popular in education, similar to how popular multimedia is today, as the devices that allow for such experience are becoming increasingly popular and more affordable and as more and more technical solutions to support such technologies are proposed [5, 6, 16].

2.3 Virtual Labs

Virtual labs refer to a set of electronic resources which provide a virtual working environment that allows to perform experiments without the need of any actual physical presence. They offer rich environments for learners to interact and use virtual objects and apparatus, through a software interface. Virtual labs offer a solution to the limitations of traditional practical classes which are resource intensive both in terms of personnel and maintenance.

Diverse virtual labs are in use world-wide, including some which target science, technology, engineering and mathematics (STEM) education.*ChemCollective*[1] is a Carnegie Mellon University virtual lab used to teach chemistry to college and high school students. Apart from the virtual labs, there are also available scenario-based learning activities, tutorials, and concept tests. *SpongeLab*[2] is a virtual lab based on a platform that provides students and educators with online free or premium resources for teaching and learning basic sciences and biology. The platform offers digital content for course development, online tools to create and share lessons and educational material and assessment tools.

Many US digital libraries and educational projects have joined the *National Science Digital Library* (NSDL)[3], which supports development of a digital online library of teaching and learning resources oriented to STEM disciplines. *TeachEngineering*[4], *Howtosmile*[5] and *Open Learning Initiative (OLI)*[6] areamong important NSDL projects. For instance, *TeachEngineering* is a National Science Foundation (NSF)-funded project which provides "*a searchable, web-based digital library collection populated with standards-based engineering curricula for use by K-12 teachers and engineering faculty to make applied science and math come alive through engineering design in K-12 settings. The TeachEngineering collection provides educators with free access to a growing curricular resource of activities, lessons, units and living labs*". OLI is a NSF-funded Carnegie Mellon project which offers an open platform to provide online content such as simulation environments, virtual labs, etc. and personalized learning to its users. The system analyzes the user experience and provides a personalized feedback to improve student-teacher interaction and maximize the success rate in the learning path.

In EU context, employing technology-enhanced teaching practices and methodologies is fundamental and several educational projects are funded, including *inGenious*[7], *iTec*[8], *Go-Lab*[9] *and NEWTON*[10]. The first three EU projects indicated are mainly focused on the development of digital repositories, and virtual labs or on experimenting new technology-enhanced teaching practices. NEWTON addresses all these aspects under a common umbrella and builds a platform NEWTELP[11] which deploys them. More details about the NEWTON project are presented next.

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[11] NEWTELP Website, http://newtelp.eu/, Accessed: July 8th 2018.

3 The NEWTON Project

NEWTON is a large European innovation action project that looks at how to use latest technological innovations to help students learn about science, technology, engineering and mathematics (STEM). It is funded by the EU Horizon 2020 programme and involves 14 academic and industry project partners from around Europe. The NEWTON project partners have designed different innovative technologies and are deploying and testing them out in various learning environments.

NEWTON technologies include solutions for adaptation and personalisation of content creation, distribution and presentation in order to increase learner quality of experience, improve learning process, and potentially increase learning outcome. Games and gamification are used to stimulate and motivate students, augmented reality allows learners to access computer generated models of scientific content, while interactive avatars guide students with special learning needs in a manner which suits them the best. Virtual and fabrication learning labs allow students to experiment in simulated environments and eventually transform their solutions into real life products. Finally and not the least important, multi-sensorial media (or "mulsemedia") helps engage three or more human senses in the learning process, including smell and touch. Innovative pedagogies such as 3D interactive educational games [9], flipped classroom [4], virtual labs-based teaching and learning, enhanced learning experiences through augmented and virtual reality, gamification, and personalised learning path through educational content are used by NEWTON learners.

Fundamentally, in the NEWTON project, these new technologies are deployed under the same umbrella: there is a newly built common platform called NEWTELP (http://newtelp.eu). NEWTELP allows educational content to be stored and delivered to learners using these NEWTON technologies as part of real life pilots to see whether and how they help students to engage more with STEM subjects. NEWTON pilots target primary and secondary schools, university and vocational institutions. There are over thirty NEWTON pilots on various technologies, among which three are large scale deployments on Programming, Gamification and Earth science. The latter is labelled "Earth Course" and focuses on primary school education across Europe.

Earth Course consists of eight separate sessions in each school and includes a set of educational applications, developed as part of the NEWTON project in an effort to attract students to STEM subjects, which cover a set of topics in the areas of Atmosphere, Geosphere, Biosphere and Astronomy. The main applications employed in this pilot are:

- Water Cycle in Nature, focusing on precipitation formation and related topics, such as vaporisation, evaporation and condensation [2];
- Wildlife, focusing on a set of terrestrial animals, such as deer, brown bear, lynx, wolf, wild boar, fox, hare and moose;
- Sea-Life, focusing on the aquatic world and presenting educational material on sea creatures such as sharks, stingrays, dolphins, puffer fish, jellyfish, octopus, orc, turtle, clownfish, seahorse;
- Final Frontier, which presents the Solar system in two parts: a game focusing on a set of astronomical bodies situated closest to the Sun: Mercury, Venus, Moon and Mars, and a virtual lab concentrating on the large gaseous planets: Jupiter, Saturn, Uranus and Neptune; and

- Geography application, which is focused on educational content about Ire-land and United Kingdom, including its monuments and archaeological sites.

This chapter focuses on the Final Frontier Game and describes the results obtained following its deployment as part of a real life pilot in an Irish primary school. Next the game, testing methodology, practical deployment and results are presented in separate sections.

4 The Final Frontier Game

4.1 Game Description

Final Frontier [9] is an interactive 3D educational video game about space for children up to 12 years old. The game supports knowledge acquisition on Solar system planets (i.e. Mercury and Venus were targeted in this study) through direct experience, challenges and fun. The topics coved by the game are part of the Geography curriculum, section “Planet Earth and Space”, defined for the primary school in Ireland. The game has different levels, each level containing different models and landscapes. In each level, the game requires meeting a game objective (i.e. mission), collection of stars and meteorites and has constrains e.g. coolant time. Information regarding the number of stars and meteorites collected, coolant time and game level mission is displayed on the screen.

Once a level is completed, the player must answer correctly a multi-choice question in order to be able to progress to the next level. The player is allowed to try to answer the question multiple times if a wrong answer is provided.

The game starts by bringing the player on a spaceship where he game mission is explained. There are two activities that the player has to complete during the first activity, the player is instructed to visit the first planet, Mercury. The game goal related to this planet is to explore the environment and to collect five meteorites hidden in the craters that exist on Mercury (see Fig. 1). The player may use the jetpack to get in and out of the craters. An avatar provides extra information (facts) about the planet during the play time.

Figure 2 illustrates how the level mission as well as the number of meteorites and stars a player has collected are displayed on the screen for the entire duration of playing a level.

Once the mission on Mercury was completed, the player returns to the spaceship, in the puzzle room where he/she must answer a question (e.g. What is the closest planet to the Sun?).

Fig. 1. The goal of the mission to Mercury [40].

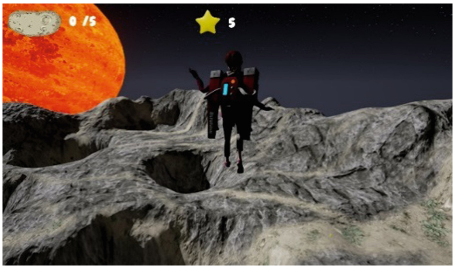

Fig. 2. The player using jetpack on Mercury [40].

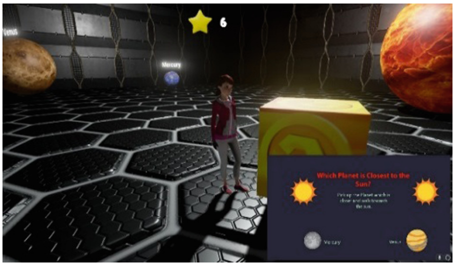

Fig. 3. Puzzle room and the question about Mercury [40].

Fig. 4. The objective of the mission to Venus [40].

Fig. 5. The player on Venus planet [40].

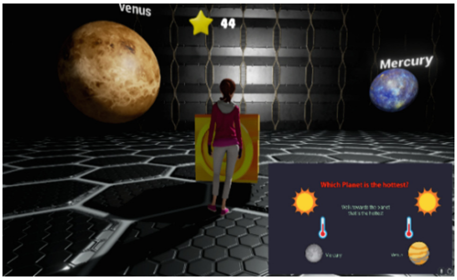

Fig. 6. Puzzle room and the question about Venus [40].

A screenshot of this game activity is presented in Fig. 3. The aim of this mini-quiz is to check player's knowledge about Mercury. The player interacts with the game environment when answering the question by picking up the correct object (e.g. planet Mercury) and placing it beside the Sun.

Once this question is answered correctly, the player is awarded a key that is used to open a door on the spaceship and progress to the next level.

The second level is associated with another activity which requires the player to explore the planet Venus and complete a given task. The mission is to traverse the Venus environment without letting their cooldown bar get to zero. Buildings called igloos may be used to recharge their coolant supply (see Fig. 4).

Next, the player is teleported to the Venus planet surface. There are four buildings (igloos) that the player may enter while crossing the terrain. The cooldown bar depletes when traversing the planet surface, which is very hot (Fig. 5), but regenerates when the player enters any of the buildings. While traversing the terrain, the player may collect stars that are added up to the overall stars' score. Facts about Venus are displayed during the play time.

Once the player reaches the fourth igloo, he/she is returned to the spaceship, into the puzzle room and asked to complete the second puzzle. A multi-choice question about Venus (see Fig. 6) must be answered correctly in order to complete this level.

The puzzle asks the player to identify which planet is the hottest in the Solar system. Three planets are displayed. The player must walk towards the planet that represents the correct answer. Once this is done the game is complete. The overall number of collected starts is also displayed.

4.2 Game Design Methodology

The methodology for designing the Final Frontier game [9] is based on that described in [23]. However, two steps related to the learning puzzle such as the general description of the learning puzzle and detailed description of the learning puzzle were added.

The authors believe that recall is a very important step in the learning process. Moreover, the recommendations on efficient game design proposed by [42] were taken into account.

The game design methodology proposed in this research is composed of the following steps:

- specification of the pedagogical objectives,
- choice of the game model,
- general description of the scenario and virtual environment,
- general description of the learning puzzle,
- choice of a software development engine,
- detailed description of the scenario,
- detailed description of the learning puzzle,
- pedagogical quality control, and
- game distribution.

Specification of the Pedagogical Objectives: The proposed 3D interactive educational game shall be used to teach concepts on the solar system in primary schools. The first step of the conception phase consists of defining the concepts that must be learned by the students. For this reason, the authors worked with teachers from European primary schools that teach the Geography subject to make sure that the designed game covers the required topics specified in the curriculum. The pedagogical objectives of the game were defined and presented in Table 1.

Table 1. LOs of the final frontier game [9].

Planet	LOs
Mercury	- Closest planet to the sun (LO1) - Planet with the most craters (LO2) - Smallest planet (LO3)
Venus	- Hottest planet due to the greenhouse effect (LO1) - Spins opposite direction to Earth (LO2) - High Gravity cannot jump very high (LO3)

Choice of the Game Model: Once the pedagogical objectives were defined, *Adventure* was selected as the game model for the *Final Frontier*. The *Adventure* game model involves the player assuming the role of the protagonist in the game, exploring the environment and completion of puzzles in order to progress. Collectable objects such as stars and meteorites are also included. The jetpack allows the player to go higher than the jump. The puzzle embedded in the game requires the player to complete various tasks in order to progress through the game. The collectable stars are used to guide the player and encourage him/her to explore the environment. The meteorites are used on the Mercury planet as a collectable to gauge the players' progress. The cooldown feature is used on Venus and gives the player a challenge, as they go through the level.

The game design has considered three areas: the spaceship where the game starts and finishes and where the player goes back to after visiting a planet; planet Mercury which the player visits during the first activity; and planet Venus that hosts the second activity to be completed.

The *Adventure* game model is one of the most popular among children. The children get more immersed and motivated when they play adventure games over other types. Moreover, the *Adventure* game model involves a linear story that can be easily defined in the game. Various gameplay features such as jetpack, puzzle solving, collectable stars and meteorites, cooldown bar were also defined in this game mode.

General Description of the Scenario and Virtual Environment: The aim of this part is to structure the pedagogical scenario and match it up with a fun based scenario. The main focus was to make the game familiar to the learners. The characters are simple human characters so the player can easily interact with. The story of the game is that the player is on a field trip, and he/she visits some planets. The player is assigned a task to do on each planet and learns implicitly facts about the planet while playing.

General Description of the Learning Puzzle: When the player completes a given task, he/she is brought back to the spaceship to solve a puzzle and when successful, to progress to the next level. The puzzle learning was added because it was believed that active recall is a principle of efficient learning. Many studies demonstrate the role of active recall in consolidating long-term memory e.g. [38].

Choice of a Software Development Engine: Concerning the game development engine, Unreal Engine 4 or Unity, two of the most popular game development engines, can be used. Unreal Engine 4 was used in this game development due to its graphic potential, especially as it was aimed to give to the player the most realistic environment of the planets.

Detailed Description of the Scenario: This step involves the illustration of each scene with all the details and interactions to be integrated into the game.

Detailed Description of the Learning Puzzle: The game has two puzzles that correspond to the two planets. Once the puzzle is answered correctly the player is allowed to go to the next planet. The player is allowed to try to answer the puzzle multiple times if a wrong answer was given.

Pedagogical Quality Control: The developed game was shown to the teacher to validate it and to approve the pedagogical quality of the game. Feedback was considered and the game was improved.

Game Distribution: Once the teacher was satisfied and the game was approved, the game was ready to be distributed to the students in the class.

5 Case Study

The goal of the research study [9] was to investigate learner experience when the Final Frontier game was used in the class to teach scientific knowledge of the planets from the Solar system to primary school children.

This section presents the evaluation methodology applied, case study set-up and results analysis for of the collected data.

5.1 Research Methodology

The evaluation included a group of children who were taught by using the Final Frontier game. The learning activity took place in class, during the normal hours of study. A total of 53 children of age 9–10 years from Saint Patrick Boys National School located in Dublin, Ireland took part in the case study. Team members from the National College of Ireland and Dublin City University (DCU) have prepared and helped perform the tests.

The evaluation meets all Ethics requirements (Table 2). Prior to running the case study, the Ethics approval was obtained from the DCU Ethics Committee and all required forms were provided to the children and their parents, including informed consent form, informed assent form, plain language statement and data management plan. These documents include a detailed description of the testing scenario, as well as information on study purpose, data processing and analysis, participant identity protection, etc.

The flow of the evaluation is illustrated in Fig. 7 that presents in details the steps followed by the researchers. It can be seen that prior to beginning the evaluation, the consent forms signed by parents were collected. Then the children were introduced to the research case study and asked to review and sign the assent form. The children had roughly 20 min to play the game or till they finished the game before doing a survey.

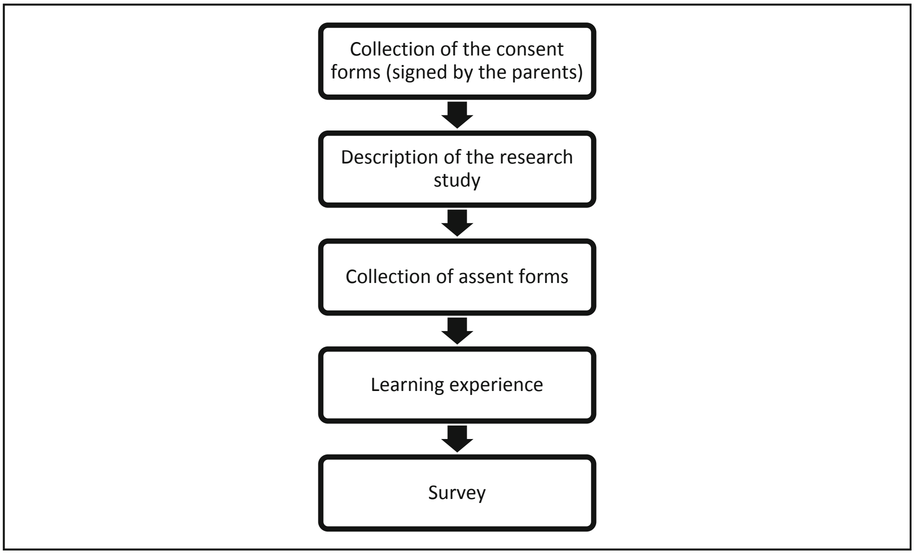

Fig. 7. Evaluation process [40].

Table 2. Survey questions [9].

Question	Answer/Scale
Q1. The video game helped me to better understand the characteristics of different planets	- Strongly Disagree, - Disagree, - Neutral, - Agree, - Strongly Agree
Q2. The video game helped me to learn easier about planets	- Strongly Disagree, - Disagree, - Neutral, - Agree, - Strongly Agree
Q3. I enjoyed this lesson that included the video game on planets	- Strongly Disagree, - Disagree, - Neutral, - Agree, - Strongly Agree
Q4. The quizzes that I did in the game helped me better remember what I learned	- Strongly Disagree, - Disagree, - Neutral, - Agree, - Strongly Agree
Q5. The video game distracted me from learning	- Strongly Disagree, - Disagree, - Neutral, - Agree, - Strongly Agree
Q6. I would like to have more lessons that include video games	- Strongly Disagree, - Disagree, - Neutral, - Agree, - Strongly Agree
Q7. What did you like most about the game?	Students to provide their feelings toward the experience
Q8. Comments/Suggestions (optional)	Students to provide their comment if they wished
Q9. What way of learning you would like (tick one answer)?	- Teacher based learning - Computer game based learning

The case study investigated the learner experience with the game and the game usability. A learner satisfaction questionnaire assessing student level of experience and game usability was collected. Standard emojis were associated with each answer to the questionnaire's questions.

5.2 Results Analysis

5.2.1 Micro-IHM Analysis

Learner experience in using the *Final Frontier* game was investigated and evaluated by questions Q1 to Q6 in the survey. The experience was analysed in terms of number of *Strongly Agree/Agree* answers for Q1, Q2, Q3, Q4, and Q6 and *Strongly Disagree/Disagree* for Q5.

The overall learner experience of children was excellent (see Table 3). 92.5% of children confirmed that the video game helped them to better understand the characteristics of the two planets. 88.8% of children thought that the video game helped them to learn easier about planets. 98.1% of students enjoyed the lesson that included the video game. 84.9% of children agreed on the fact that quizzes embedded in the game helped them better remember what they have learned. 70.1% of children disagreed that the video game distracted them from learning. 96.2% of children expressed that they would like to have more lessons that include video games.

Table 3. Children answers on the user experience survey [9].

	SD	D	N	A	SA
Q1	0	0	7.5%	60.5%	32%
Q2	0	0	11.2%	45.4%	43.4%
Q3	0	0	1.9%	19.1%	79%
Q4	0	1.9%	13.2%	52.9%	32%
Q5	45.4%	24.7%	15%	3.7%	11.2%
Q6	1.9%	0	1.9%	7.5%	88.7%

Note that for clarity reasons, in Table 3, SD refers to *Strongly Disagree*, D refers to *Disagree*, N refers to *Neutral*, A refers to *Agree*, and SA refers to *Strongly Agree*.

5.2.2 Game Usability

The game usability of the *Final Frontier* was also analysed through Q7, Q8 and Q9 from the survey.

An analysis of the answers provided for Q7 and Q8 shows that 92.6% of children mentioned that they have enjoyed the game, in particular the fun aspect, learning aspects, stars and meteorites collection, avatar, use of jetpack, and interactive puzzle room.

Regarding Q9, 94% of children mentioned that they prefer computer game-based learning during the normal teaching class, which is an outstanding result for the deployment of this game.

6 Conclusion

The growing importance of Science, Technology, Engineering, Mathematics (STEM) education requires innovative teaching and learning approaches in order to increase the number of students that follow STEM career. This paper addresses the problem of motivating, engaging, and improving learning experience of students in the STEM field. NEWTON is an ambitious EU Horizon 2020 funded innovation action project that seeks to integrate innovative technologies in STEM education. A novel interactive and immersive video game (Final Frontier) was designed as part of this project. A case study that involved 53 children of age 9–10 years from Saint Patrick Boys National School located in Dublin, Ireland was run in order to assess how the game supports knowledge acquisition about the Solar system through direct experience, active recall, challenges and fun.

A survey that gathered information about learner experience with the game, and game usability was distributed to the children after they played the game. An analysis of the survey answers shows that over 90% of the children were satisfied with the game usability and they enjoyed the game. The children have also appreciated various game features including the fun aspect, learning aspects, stars and meteorites collection, avatar, use of jetpacks, and the interactive puzzles. The game will be extended to include adaptive features such as personalised learning paths and extra learning support when a wrong answer is given to a puzzle. Future tests will include the deployment of the Final Frontier game through the NEWTELP platform developed as part of the NEWTON project [29] in different European primary schools. Usability, learner satisfaction and knowledge achievements analyses will be performed across the countries.

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